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PENNSYLVANIA
GEOLOGICAL SURVEY
FOURTH SERIES

BULLETIN C 9

GEOLOGY AND MINERAL RESOURCES OF BUCKS COUNTY PENNSYLVANIA

INTRODUCTION
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MESOZOIC ROCKS
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DEPARTMENT OF INTERNAL AFFAIRS
MISS GENEVIEVE BLATT, *Secretary*

TOPOGRAPHIC AND GEOLOGIC SURVEY
CARLYLE GRAY, *State Geologist*

1959

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BUCKS COUNTY, PENNSYLVANIA

Chapter I

INTRODUCTION

by

Bradford Willard

Contributors

Dr. Benjamin L. Miller, for over thirty years professor and Head of the Department of Geology at Lehigh University, was senior author of the Pennsylvania Geological Survey reports on Northampton and Lehigh Counties. At the time of his death, 1944, Dr. Miller had just commenced work on a similar report on Bucks County. The late Dr. George H. Ashley, then State Geologist of Pennsylvania, assigned the present author to bring to completion Professor Miller's unfinished studies. This was accordingly undertaken and, as time permitted, carried on for over seven years. Subsequently the completed report was submitted to the Survey.

When the preparation of this report on the geology of Bucks County was started. it was not appreciated that so many geologists were interested in the County. As this situation became apparent, the several workers were invited to join forces in a cooperative report.

Dr. Dean B. McLaughlin of the University of Michigan has probably spent more time on the geology of Bucks County than all others. To him is due credit chiefly for the mapping and interpretation of the Newark group. Willard made some contributions to the study of the Newark group in the northwestern part of Bucks County where McLaughlin had not had time to work.

Professor E. H. Watson of Bryn Mawr College mapped and studied the petrography of the basic intrusives of the northern part of the Triassic rocks, the contact metamorphic zones associated with these bodies and criticized Chapter II, Metamorphic Rocks. Mr. Thomas E. Stephenson made a study of the Triassic intrusives east of Coopersburg, Pennsylvania.

Data on the basic intrusives along the lower part of the Delaware Valley were compiled chiefly through studies of Dr. J. D. Ryan.[1]

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[1] This section of the Bucks County Report is based in part on his thesis, "The Petrology of the Diabase Intrusions of the Delaware River Valley" (1948). Field work and laboratory studies were sponsored by the Pennsylvania Topographic and Geologic Survey. The Haycock sill was not included in this study.

In 1952, additional samples of syenite from the Mount Gilboa sill in New Jersey and samples of diabase, syenite and hornfels from the Haycock sill were obtained. The entire collection was restudied.

Areal mapping of the Haycock sill and associated hornfels and the small dikes in the southeastern half of the County geologic map is by Dr. E. H. Watson and Dr. D. B. McLaughlin. The remaining intrusives and hornfels were mapped by Dr. Bradford Willard and Dr. D. B. McLaughlin with the assistance of Dr. Ryan.

While a graduate assistant at Lehigh University during the summer of 1947, Ryan was employed on the Pennsylvania Topographic and Geologic Survey and made these studies the subject of his master's thesis. Subsequently, Ryan cooperated with Dr. E. H. Watson on the Triassic igneous rocks. Dr. Jacob Freedman re-wrote Chapter II, Metamorphic Rocks. The material for this study was derived mostly from the literature, but in part from some of Dr. Willard's manuscript and conferences with Watson.

The mapping and stratigraphic interpretation of the Paleozoic formations was done by Dr. Bradford Willard of Lehigh University, Professor B. F. Howell of Princeton University, and Mr. Henry B. Roberts of the Wagner Free Institute of Science. In this Dr. Willard had some assistance from Dr. Ryan and cooperation from Dr. Watson and Dr. McLaughlin. Mr. R. G. Petersen, a former graduate student at Lehigh University, studied the petrography of the Lower Cambrian quartzites. Mr. Ross H. Lessentine restudied the Cambrian limestones in the Buckingham area as his master's thesis at Lehigh University.

Professor B. F. Howell who had a unique collection of Cambrian Invertebrate fossils from east-central Bucks County, consented to describe his material for the report. Because of the significance of this contribution, it was decided to publish it as a separate account entitled "Upper Cambrian Fossils of Bucks County, Pa." Mr. Henry B. Roberts of the Wagner Free Institute contributed studies of Cambrian algae from Bucks County.

Dr. H. R. Gault of Lehigh University undertook the study of the economic geology of Bucks County exclusive of water supply. He was assisted during the summer of 1948 by Mr. Joseph H. Goth, at that time a graduate student at the University of Pittsburgh. Mr. D. O. Beeler, while a graduate student at the Lehigh University, studied some of the iron ores. Dr. E. W. Tooker studied the barite deposits as his master's thesis at Lehigh University. Mr. David W. Greenman of the Ground Water branch of the United States Geological Survey has prepared a report on water supply conditions in Bucks County which has been published separately (1955).

The unconsolidated materials in the southern part of Bucks County and along the Delaware River received some attention from the late Professor Freeman Ward of Lafayette College. Professor Ward prepared reports for the Pennsylvania Topographic and Geologic Survey. These have been freely drawn upon in Chapter V, Late Pleistocene Deposits, by Dr. Louis C. Peltier.

The study of the Pleistocene deposits was carried out during the field seasons of 1948 and 1949. In 1948 a reconnaissance of the Delaware Valley was made with Dr. Paul MacClintock under a grant made available by the Department of Geology, Princeton University. In 1949 a more detailed study of Bucks County was carried out for the Pennsylvania Topographic and Geologic Survey.

Dr. Bradford Willard and Mr. Meredith E. Johnson, State Geologist of New Jersey, visited Dr. Peltier in the field. Dr. Paul MacClintock maintained close contact with Dr. Peltier throughout the 1949 season and visited the field with him several times. He made many valuable suggestions concerning both technique and interpretation.

Others who have made contributions of time, thought and data should be mentioned. Dr. R. E. Stevenson, while instructor at Lehigh University, compiled information on pigmentation of the black argillite of Lockatong lithofacies. Professor E. T. Wherry of the University of Pennsylvania prepared the discussion of the Triassic fossils. Mr. Wilhelm Bock of the Philadelphia Academy of Natural Sciences made suitable suggestions about the Triassic flora, its possible correlation with that of Europe, and has generously collaborated with Professor Wherry. While a graduate assistant at Lehigh University, Dr. L. F. Dellwig, studied the pebble beds of Stockton lithofacies. A similar study by another Lehigh student, Mr. John T. Palmer, of the fanglomerates on the New Jersey side of the Delaware River has been quoted. Other Lehigh students who have worked on problems in Bucks County and made minor contributions are Messrs. R. B. Palmer, G. V. Carroll, William A. Heck, Neil L. Ross, R. E. Bergenback, R. N. Taylor, Frank J. Anderson, J. Peter Trexler, James A. Noel, David K. Ford, Stanton H. Davis, William J. Otten, A. W. Schlottman, C. P. Miller, Charles W. Yost, Robert Walters, and M. M. Chow. Robert C. Gerhard, University of Chicago, did a petrologic study on rocks of the Newark group of Eastern Pennsylvania, including Bucks County. The studies of metamorphic rocks in the southern part of Bucks County made by Drs. Judith Weiss and Elizabeth Armstrong while at Bryn Mawr College have been drawn upon.

On several occasions Mr. M. E. Johnson, and the late Mr. Henry F. Herpers of the New Jersey Geological Survey arranged to meet with Dr. Willard in the field and discuss problems in New Jersey directly related to those encountered west of the Delaware River. Other field conferences were held with Professor Watson, Dr. Peltier, Dr. R. C. Stephenson, formerly of the Pennsylvania Topographic and Geologic Survey, and Professor Paul MacClintock of Princeton University.

Dr. Bradford Willard of Lehigh University in 1958 and Dr. Jacob Freedman of Franklin and Marshall College during the summer of 1956, edited this report on the geology of Bucks County.

Finally, thanks are due to Miss Leona Tretheway in the early stages and Mrs. Regina Engler in the later stages for their patience in typing the manuscript. Messrs. J. A. MacFayden and Gates Willard, part-time workers on the Pennsylvania Topographic and Geologic Survey, prepared a number of illustrations.

LOCATION, GEOGRAPHY, AND PHYSIOGRAPHY

Location

Bucks County is located in southeastern Pennsylvania. It lies approximately between the 40°3′ and 40°37′ parallels of north latitude and the 74°43′ and 75°29′ meridians of west longitude. The northwestern boundary is Northampton County toward the northeast and Lehigh County to the northwest. On the east the south-flowing Delaware River separates Bucks County and Pennsylvania from New

Jersey. The river swings sharply west below Morrisville, Pennsylvania, to form the southern boundary of Bucks County and separate it from Burlington County, New Jersey. The southwestern limit of Bucks County is Montgomery County except for a few miles at the southeast end where Philadelphia County borders it.

Bucks County includes approximately 610 square miles in a roughly rectangular block whose longer axis trends northwest-southeast. Its greatest length is slightly over 40 miles, its maximum width a little more than 20 miles.

Surface features

Bucks County enters three of the major physiographic provinces of the United States. Its northern corner is included in the Reading Prong of the New England province. The extreme southern portion lies in the Coastal Plain province. The intermediate area is that part of the Piedmont province designated as the Piedmont Upland (Fenneman, 1946). Most of the central part of Bucks County occupies a portion of the Triassic Lowland section.

The maximum relief of Bucks County is over 960 feet, ranging from sea level in the south to the crest of Flint Hill along the Lehigh-Bucks county line in the northwest. Haycock Mountain, the highest peak entirely within Bucks County, reaches 960 feet above sea level. Other prominent ridges and low mountains rise in the northern and northeastern parts of Bucks County.

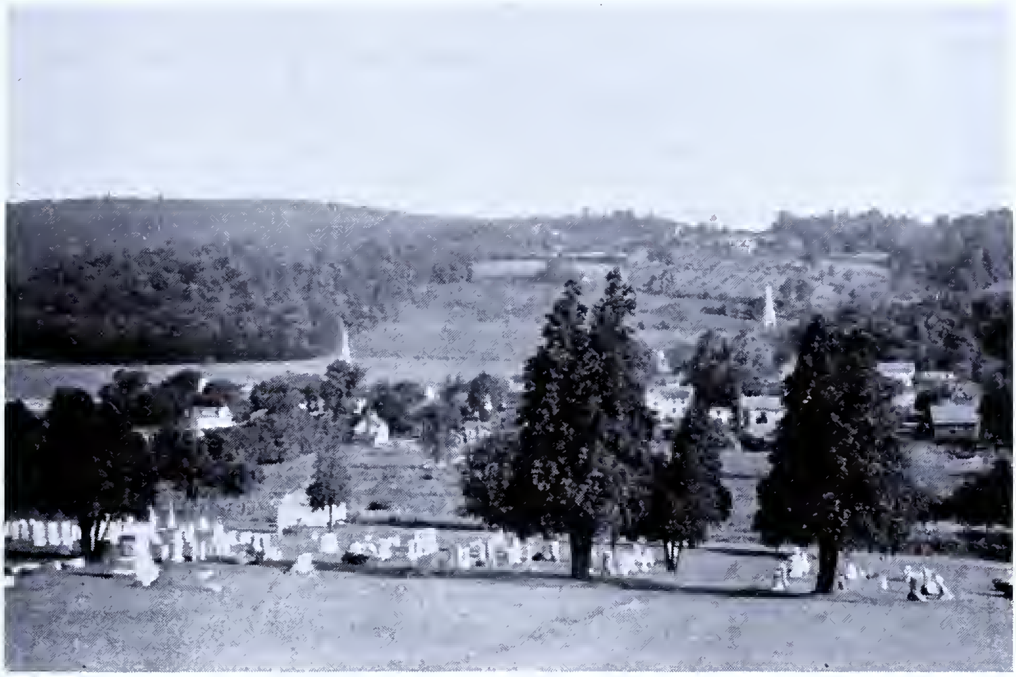
The northern boundary is drawn along an irregular ridge, surmounted by several rounded, high points, of which Flint Hill in Springfield Township is an example (Plate 1). These consist of Pre-Cambrian and Cambrian crystalline rocks and Triassic fanglomerates. A similarly-supported, smaller area lies parallel to the first and extends from the Delaware River four or five miles westward. Rattlesnake, Mine, Chestnut and Buckwampum Hills are high points on it.

The larger Triassic intrusives form elevations referred to as "trap ridges." In the northeast is Coffman Hill, a plateau-like area with one point 826 feet above sea level. To the west of Coffman Hill, Haycock Mountain reaches an elevation of 960 feet at its northeastern peak and trails off southwestward into lower hills. Along the Delaware River in the east-central part of Bucks County are three prominent ridges, Solebury Mountain (480 feet), Bowman Hill (380 feet) and Jericho Mountain (420 feet). There are extensions of similar trap hills in New Jersey.

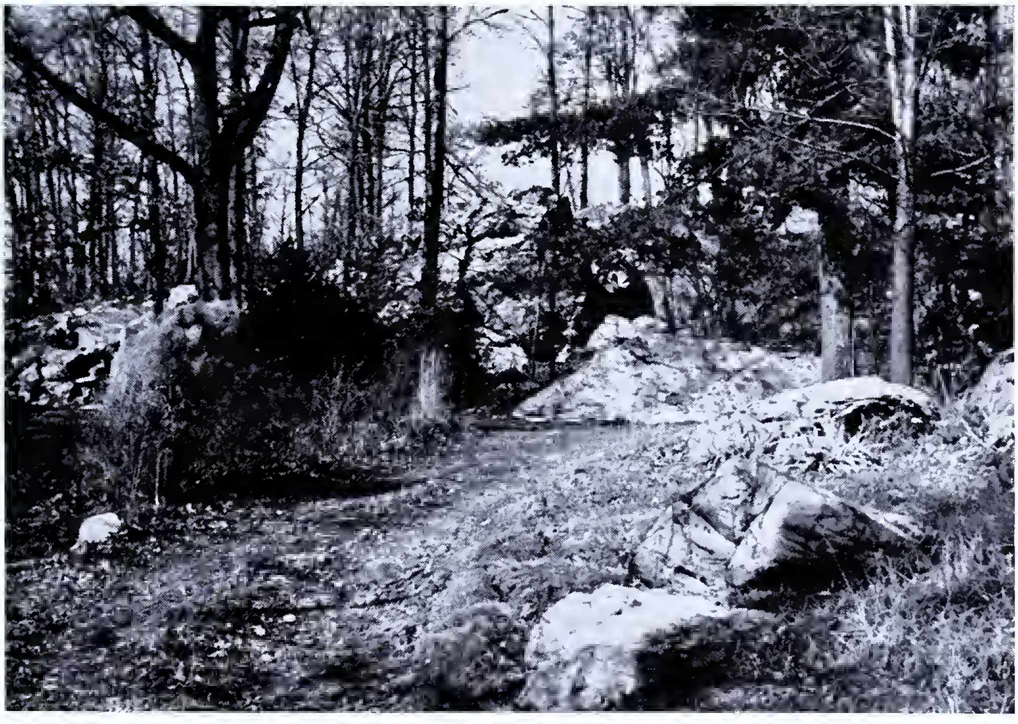
Southeast from Doylestown, Cambrian Chickies Quartzite supports two east-west trending ridges, Buckingham Mountain (520 feet) and Little Buckingham Mountain (300 feet) (Plate 3, B). Many small ridges are supported either by the conglomerates of the Stockton Lithofacies or by argillite of Lockatong Lithofacies of the Triassic.

The lower-lying parts of Bucks County are rolling. Durham (Cook) Creek occupies a valley cut into Paleozoic limestones, and a similar valley lies north of the Buckingham Mountains. The flat to rolling Triassic areas are locally dissected by such entrenched streams as Tohickon and Neshaminy Creeks. The Coastal Plain is a narrow, low, flat area adjacent to the Delaware River in the south and continuous

PLATE 3



A. Western end of Durham Valley at Springtown, view north from Bitts Hill; limestone valley in middle distance, Kohlenberg ridge (Northampton County) in distance supported by Pre-Cambrian gneisses. Photo by B. L. Miller.



B. Outcrops and boulders of Chickies Quartzite near crest at west end of Buckingham Mountain. Photo by B. L. Miller.

with terraces and flood plains upstream. From Morrisville to the western boundary of Bucks County, a belt of Cambrian Chickies Quartzite and Pre-Cambrian metamorphosed rocks produces small hills.

The physiographic features in Bucks County are controlled in part by the periglacial erosion but dominantly by stream erosion. Glaciofluvial and fluvial deposits are mostly confined to the Delaware Valley and the southern part of Bucks County. Of special physiographic interest are the high bluffs along the Delaware River from Upper Black Eddy to Kintnersville. They are cut in Triassic sediments capped by the Coffman Hill diabase sheet. The bluffs rise almost vertically with a relief of 250 to 280 feet.

Drainage

The drainage in Bucks County runs eastward into the Delaware River and westward into the Schuylkill. The Delaware watershed embraces about 75 percent of Bucks County; the Schuylkill, the remaining 25 percent. Many small streams called "creeks" or "runs" flow into the rivers. The following is a partial list of the principal streams from north to south in Bucks County:

- Tributaries of the Delaware River
  - Durham (Cook) Creek[1]
  - Gallows Run
  - Tinicum Creek
  - Tohickon Creek
  - Gaddes Run
  - Paunaucussing Creek
  - Aquetong Creek
  - Dark Hollow Run
  - Pidcock Creek
  - Jericho Creek
  - Houghs Creek
  - Dyers Creek
  - Buck Creek
  - Brock Creek
  - Biles Creek
  - Scotts Creek
  - Common Creek
  - Mill Creek
  - Neshaminy Creek and its tributaries
  - Poquessing Creek
- Tributaries of the Schuylkill
  - Unami Creek and its branches
  - Ridge Valley Creek
  - Perkiomen Creek

Most of the tributaries have smaller named, or unnamed, affluents. The only navigable stream is the Delaware River below Trenton. Along it bottom lands, terraces and islands are common and subject to floods. The flood of 1903 is reported to have covered these features compeltely; that of 1936 was less severe. The smaller streams often overflow their banks.

Population and Industry

The population of Bucks County, according to the Federal Census of 1950, was 144,620, an increase of 34.3 percent over the census of 1940. About one-third of these people live in the principal towns, Bristol, Doylestown (the County Seat), Langhorne, Morrisville, New Hope, Newtown, Perkasie, Quakertown, Sellersville and Yardley. Agriculture, largely devoted to truck and general farming, and poultry raising, are the chief industries of Bucks County. In 1952 the United States Steel Corporation opened its large plant at Morrisville, and nearby Levittown, Pennsylvania, has grown rapidly as a residential area for steelworkers.

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[1] The names Cook and Durham have been both applied to the stream as long ago as 1858 (Rogers). Both names appear on recent maps, but Durham seems to be preferred locally.

Climate

The climate of Bucks County has been described in the Bucks County Soil Survey report (Burke and others, 1936, p. 9-10) as follows:

> The climate of Bucks County may be characterized as continental, although it is likely that some influence is felt from the Atlantic Ocean, which is only about 100 miles away. It may be described as quite temperate, as it lacks the extremes of winter and summer temperatures.
>
> The winters are not continuously cold, as the temperature fluctuates within wide limits; but there is considerable snow. Spring (March, April, and May) is more often characterized by extremes in temperature than the fall season and is generally colder and more uncertain. The summers are usually mild and pleasant. There are occasional hot spells when the weather is rather oppressive, but these are generally of short duration. The approach from summer to fall is generally gradual, and the fall season is one of the most pleasant parts of the year. Although the weather in November may be cold, it is bracing and invigorating.
>
> The average snowfall for the year is given as 36.0 inches, and this is restricted to the late fall, winter, and early spring months. The mean precipitation for the year is reported as 46.93 inches, with a low of 27.73 inches for the driest year (1875) and a high of 68.92 inches for the wettest year (1889). According to some of the older residents, there has been less water in the major streams of the county during the last 15 years, particularly in Neshaminy, Perkiomen, and Tohickon Creeks. They also report that the general water table has been lowered and that crops are not generally so good as formerly. The water supply of the farms is drawn from shallow and deep drilled wells. The water supply of the towns comes from streams, and the water is pumped, filtered, and treated with chlorine.
>
> May 29 is given as the date of the latest frost recorded in spring, and September 15 as the earliest in fall. The average dates, which represent more normal conditions, are May 3 and October 5, and give an interfrost period of 155 days, which is ample for the production of a wide range of crops.
>
> Local periods of drought are not uncommon and protracted dry spells cause considerable loss in production, especially on well-drained lands, but more particularly on the thin, shallow soils.

Soils

The following statements are quoted from the Bucks County Soil Survey report (Burke and others, 1936, p. 4):

> The soils of Bucks County as surveyed comprise 51 soil types, 29 phases, 1 complex, and 6 miscellaneous land types. These are grouped in the section on Soils and Crops, according to character of parent materials and physiographic province or topographic position. The three principal categories are soils of the Piedmont Plateau, soils of the Coastal Plain, and soils of the stream terraces and bottoms.
>
> In the group of soils of the Piedmont Plateau, the Bucks and Penn soils are developed from Indian-red shales and sandstones; the Lansdale, Steinburg, and Lehigh soils are developed from gray and yellow shales and sandstones; the Chester, Neshaminy Manor, Edgemont, Brandywine, Buckingham, and Califon soils are developed from a rather complex belt of rocks consisting of gneisses, arkoses, quartzites, conglomerates, and schists; the Duffield, Chalfont, Doylestown, Greer, and Captina soils are developed from dolomitic limestones and shales; the Montalto and Watchung soils are developed from intrusive rocks consisting of diabase and gabbro; and the Springtown, Annandale, and Washington soils are presumably developed from old glacial till of Jerseyan age.
>
> The soils of the Coastal Plain consist of members of the Sassafras, Woodstown, Falsington, and Elkton series.
>
> The soils of the terraces are classified in the Chenango, Unadilla, Elsinboro, and Braceville series, whereas those of the bottom lands are included in the Tioga, Bermudian, Codorus, Bowmansville, Wehadkee, and Melvin series.
>
> The miscellaneous land types include three kinds of rough stony land, based on the character of the parent rock; tidal marsh; marsh; and alluvial soils, undifferentiated.

TABLE 1.—*Normal monthly, seasonal, and annual temperature and precipitation at Quakertown, Bucks County, Pa.*
(Data from the United States Weather Bureau station at Quakertown, Elevation, 480 feet)

Month	TEMPERATURE			PRECIPITATION			
	Mean °*F.*	*Absolute maximum* °*F.*	*Absolute minimum* °*F.*	*Mean Inches*	*Total for the driest year (1875) Inches*	*Total for the wettest year (1889) Inches*	*Average snowfall Inches*
December	31.4	66	-9	3.96	2.39	2.43	5.6
January	26.9	65	-20	3.82	.50	4.58	10.6
February	28.8	80	-15	3.31	4.44	2.38	10.6
Winter	29.0	80	-20	11.09	7.33	9.39	26.8
March	37.5	84	-3	3.79	3.25	3.47	6.3
April	48.5	92	10	4.06	1.50	4.83	1.5
May	59.5	95	24	3.36	1.84	5.45	0
Spring	48.5	95	-3	11.21	6.59	13.75	7.8
June	68.4	100	37	3.91	1.87	7.31	0
July	72.6	105	42	4.68	2.25	11.54	0
August	70.5	105	37	5.09	1.69	4.76	0
Summer	70.5	105	37	13.68	5.81	23.61	0
September	64.0	97	29	3.89	.90	8.06	0
October	52.3	91	20	3.92	2.90	5.23	.1
November	41.4	78	5	3.14	4.20	8.88	1.3
Fall	52.6	97	5	10.95	8.00	22.17	1.4
Year	50.2	105	-20	46.93	27.73	68.92	36.0

General Geology

The Formations

The geologic formations of Bucks County are of varied lithology and assigned to widely separated parts of the geologic sequence as recognized in North America. In the following list of geologic systems, those in italics are represented in Bucks County.

*Quaternary**
Tertiary (?)
Cretaceous (?)
Jurassic
Triassic
Permian
Pennsylvanian
Mississippian
Devonian
Silurian
Ordovician (?)
Cambrian
Pre-Cambrian

* Quaternary is used to include sediments of glacial age and Recent deposits.

The Pre-Cambrian, early Paleozoic, Triassic and Pleistocene are exposed at the surface. The Cretaceous age for buried clay and doubtful Tertiary age for some of the unconsolidated surface sediments in the southern part of Bucks County are probably correct designations.

All three categories of rock types, igneous, metamorphic and sedimentary, are present. The chief igneous rocks are the basic intrusives, most of which are Triassic in age, and some possibly Pre-Cambrian dikes. Some rocks have been exposed to contact and dynamic metamorphism. Both marine and fresh-water sediments occur. The Triassic deposits and most of the unconsolidated deposits are alluvial. The Cambrian and Ordovician (?) marine limestones range widely in chemical composition and physical characteristics. Fossils are scarce, consisting of Cambrian invertebrates and algae, Triassic plants and animal remains. The geologic column in Bucks County is given in Table 2.

Table 2. *The Geologic Column Exposed in Bucks County*

	Thickness in feet
QUATERNARY, River terraces and flood plain deposits, chiefly in Delaware Valley silt and loess	Variable
TRIASSIC, Newark group	
Igneous rocks: basic intrusives (diabase and gabbro)	1,700 max.
Sedimentary rocks:	
Brunswick Lithofacies; red beds and fanglomerate	6,000
Lockatong Lithofacies; gray argillite, black and red shales, fanglomerate	2,000-3,000
Stockton Lithofacies; arkose, conglomerate, red beds and fanglomerate	5,000±
(All three divisions of the sedimentary rocks of the Newark group are penecontemporaneous facies. Where cut by the basic intrusives, they have undergone varying degrees of contact alteration.)	
ORDOVICIAN (?)	
Cocalico (?) Phyllite. Gray to purplish, sericitic slate and phyllite	200+
Beekmantown (?) Limestone. Blue-gray, massive, high magnesium limestone	1,000 ±

CAMBRIAN	
Conococheague (Allentown) Limestone. Alternating dark- to light-gray banded, medium-bedded, high magnesium limestone; many oölitic, sandy and cherty beds; abundant, calcareous algal beds	400 (+?)
Conococheague (Limeport) Limestone. Similar to Allentown limestone but thicker-bedded; sandy, dolomitic limestone and shaly limestone. Algal bioherms plentiful; Dresbachian invertebrates ..	400-500
Elbrook (?) (Leithsville) Limestone (Buckingham area) lithologically, buff and bluish or gray, massive to platy or shaly, high magnesium limestone, thick beds conspicuously laminated	700-900
Tomstown Dolomite (Leithsville Limestone. Gray, blue or buff, massive to platy or shaly, high magnesium limestone; sericitic shaly beds; barren (Durham area).	
Hardyston Quartzite (Durham area). Brown to gray, platy to slabby sandstone and quartzite plus yellowish jasper and conglomerate lenses. *Scolithus* is the only fossil reported	50-300
Chickies Quartzite (Buckingham and Langhorne areas). Approximate correlative of Hardyston quartzite, but distinguished by its basal member, the Hellam conglomerate. Quartzite, sandstone and conglomerate; only recorded fossils: *Scolithus* and *Olenellus*	900 +
LATE PRE-CAMBRIAN OR EARLY PALEOZOIC	
Granite gneiss, ultrabasic rocks, hornblende schist, Wissahickon Schist.	
Metamorphic complex in southern part of Bucks County may be of Pre-Cambrian or early Paleozoic age.	
PRE-CAMBRIAN	
Pegmatite dikes. Cut the Pre-Cambrian gneisses and locally the Cambrian quartzites.	
Northern area.	
Byram Gneiss. Light-gray to brownish granite gneiss.	
Pochuck Gneiss. Black to dark-gray hornblende gneiss.	
Southern area.	
Baltimore Gneiss. Metamorphic complex, largely composed of hybridized gabbro due to introduction of granitoid rocks and materials. There are dikes of metamorphosed diabase and vague remnants of early sedimentary rocks.	
Franklin Limestone. Coarsely crystalline marble with scattered graphite flakes.	

Distribution of Formations

The formations have fairly definite topographic expression. The ancient crystalline rocks of the north, the Triassic igneous intrusives, some of the Triassic siliceous fanglomerates and the Chickies Quartzite are the chief ridge-making elements. The Paleozoic limestones underlie valleys which locally have sink holes. The Triassic sedimentary rocks are expressed in rolling, open country. Unconsolidated fluviatile materials occur as terraces and flood plains along the Delaware River and some of the lesser streams and are spread across the flat, low-lying southern border of Bucks County.

The Pre-Cambrian gneisses and other metamorphic rocks of uncertain age are confined to two regions: 1) The hills along the northern border of Bucks County and Rattlesnake, Mine and Bitts Hills, south of them. 2) The southern part of Bucks County westward from Morrisville. The latter belt produces no important topographic features. Questionable Pre-Cambrian gabbro reported at the south flank of Buckingham Mountain has been authenticated.

Cambrian Hardyston and Chickies Quartzites are not found together, although of essentially identical age. The Hardyston Quartzite is confined to the flanks of the northern ridges, which have cores of Pre-Cambrian gneisses. The Chickies Quartzite and its distinctive basal member, the Hellam conglomerate, support Buckingham and Little Buckingham Mountains in the east-central part of Bucks County, and form the low east-west ridge in the Langhorne area.

The Lower Paleozoic limestones underlie two valley areas: 1) Durham (Cook) Valley, west from Riegelsville in the northern part of Bucks County, is a long, narrow, triangular synclinal basin underlain by Conococheague (Allentown and Limeport) Limestone and Tomstown Dolomite (Leithsville Limestone). 2) Buckingham Valley, an elliptical area east of Doylestown, lies along the south border of one of the major fault blocks and is formed on Cambrian and Ordovician (?) limestones with a small, triangular patch of Cocalico (?) Phyllite at its western extremity.

Triassic igneous intrusives and associated baked sedimentary zones form Haycock Mountain, Coffman Hill and lower hills in the north. Along the Delaware River from Point Pleasant southward the conspicuous ridges, Solebury and Jericho Mountains and Bowman Hill, are similarly supported. Triassic sediments underlie relatively flat, rolling country, but locally produce small ridges along the outcrops of more massive Lockatong Lithofacies or prominent conglomerate beds in the Stockton Lithofacies. The siliceous border fanglomerates form Buckwampum and Chestnut Hills, and Flint Hill, the highest point in Bucks County. The calcareous fanglomerates which lie along the south edge of the border fault make no conspicuous topographic expression.

Exposed post-Triassic deposits are limited in extent. River terraces are conspicuous along the Delaware River. Other unconsolidated deposits of varying thickness veneer the ancient metamorphic rocks and cover Cretaceous (?) and Tertiary (?) formations in the southern part of Bucks County. On the southernmost edge of Turkey Hill, south of a road crossing along the Pennsylvania Railroad track, a few square feet of varigated clay believed to belong to the Cretaceous system was at one time exposed.

Structures

The ridges in the north are anticlinal with Pre-Cambrian gneissic cores and Cambrian quartzite flanks. Durham (Cook) Creek Valley is a syncline in Cambrian limestones. Although Paleozoic rocks are much folded and faulted, lack of continuous sections prevents recognition of details. The complexity of the structure is exemplified in Figure 2 (p. 33) along the New Jersey side of the Delaware River opposite Riegelsville.

The Triassic sedimentary rocks in general dip gently northwestward. Locally a reversal is found, typically in the vicinity of the larger intrusive bodies. At such places the sediments may dip toward the igneous masses. Large, east-west trending, normal, strike faults throw the Triassic rocks into a succession of blocks tilted to the north. The fault south of Buckingham Mountain has sufficient throw to bring

Cambrian and Pre-Cambrian rocks to the surface. Along the northern border the Triassic rocks are in fault contact with older formations. A number of small faults in the Triassic rocks are nearly parallel to the main faults, but the magnitudes of most can be only roughly estimated for lack of key beds. Both igneous and sedimentary Triassic rocks are well-jointed.

A few faults trend at sharp angles to the others in the Paleozoic and Pre-Cambrian formations in the north at Springtown and Durham Union Church. Their throw is small contrasted to the great block faults, but all appear to be normal faults. In the south, the metamorphic rocks of uncertain age (Wissahickon Schist, etc.) are shown overthrust northward against the Chickies Quartzite, cutting out all of the Lower Paleozoic limestones in this area.

Age of the Structures

Inasmuch as there is general agreement in the character and trend of the pre-Triassic folds with those in the Appalachian Mountains, the folding is assigned to the Appalachian revolution. There is no information in the record of two intervals of compression that would indicate that the area had been affected by the Taconic disturbance. The southern thrust fault is also probably associated with the Appalachian orogeny. Normal faults, which produced the tilted blocks, and the smaller normal faults developed during the Palisades disturbance. Basins, associated with the basic intrusives, probably formed before the Palisades disturbance because the Flemington fault in New Jersey transects such a basin. The border fault probably underwent repeated movement during the deposition of the Newark group. The structures are chronologically summarized in Table 3.

TABLE 3. *Chronologic Summary of Structural Developments*

Palisades disturbance (late or post-Triassic)
  Normal faulting, tilting of blocks, final movement on border fault probable.
Late Triassic interval of igneous intrusion.
  Warping of Triassic sedimentary rocks during or after intrusions, in the vicinity of the large igneous bodies producing basins.
Appalachian revolution (late Paleozoic)
  General folding of the area, thrust faulting (?) in the south, followed by deposition of the Newark group.
Taconic disturbance (late Ordovician)
  No direct, local evidence.

CHAPTER II

METAMORPHIC ROCKS

by

JACOB FREEDMAN

GENERAL STATEMENT

Crystalline rocks occur in three scattered areas in Bucks County. The Durham area at the north tip, seven and a half miles long northeast-southwest and two and a half miles wide, is essentially flanked by crystalline rocks. This is the southern part of the Reading Prong which totals 6½ miles in width in Northampton and Bucks Counties. The Buckingham area in the central part of Bucks County contains Pre-Cambrian quartz diorite, which is not shown on the geologic map, because it was considered invalid at the time of the publication of Plate 2 (in pocket). The southern area is a belt seven to eight miles wide underlain by metamorphic rocks except for a long, narrow east-west section of Chickies Quartzite 0.2 to 0.3 miles in width. Much of the southern area is covered by Quaternary sediments.

In the Durham area, the crystalline rocks consist of the Pochuck, and Byram Gneisses and pegmatite. The crystalline rock in the Buckingham area was simply referred to as gabbro (Wherry, personal communication) and identified as quartz diorite by Ryan (p. 16). The southern area is underlain by Baltimore Gneiss, Franklin Limestone, metadiabase, the Wissahickon Schist, hornblende schist, altered ultrabasic rocks, and granitized areas in the Wissahickon Schist. All of these rock types are Pre-Cambrian in age with the possible exceptions of the Wissahickon Schist and the pegmatite (Table 2, p. 9).

DURHAM AREA

Distribution of rock types

The Durham area at the northern tip of Bucks County is underlain by Pochuck Gneiss, Byram Gneiss, pegmatite, Cambrian Hardyston Quartzite, Tomstown Dolomite (Leithsville Limestone) and younger Cambrian limestones. The Cambrian rocks are described in Chapter III (p. 23). The Pre-Cambrian metamorphic rocks make two parallel resistant ridges (p. 10), one in the northern part of the Durham area, the other in the southern part. In the northern ridge, a narrow strip about five miles long and two semi-elliptical patches, each 0.3 miles long, continue into Northampton County. In the southern ridge, a more irregular strip about five miles long runs between Bitts Hill and Mine Hill (Plate 3, p. 5). A separate patch underlies Rattlesnake Hill to the east. One mile west of the crest of Bitts Hill and 0.3 miles southeast of the Northampton County line, a small area of metamorphic rocks and Cambrian quartzite crops out in the Cambrian limestone without topographic expression.

In adjacent areas (Fraser, 1939; Fraser, 1941) the Pre-Cambrian rocks of the Reading Prong have been divided into a number of units.

Of these only two have been positively identified in Bucks County: Pochuck Gneiss, and Byram Gneiss. The gneisses are so intimately interlayered and the individual areas of each are so small that no attempt was made to differentiate them on the geologic map (Plate 2, in pocket).

Pochuck Gneiss

The Pochuck Gneiss was named for Pochuck Mountain in New Jersey by Wolff and Brooks (1898, p. 439). It was described by Spencer (1908), Bayley, Salisbury (Bayley *et al* 1914) in the Highlands of New Jersey, and Fraser in Northampton (1939) and Lehigh (1941) Counties. The Pochuck Gneiss is a dark-green to black, massive to foliated rock composed chiefly of hornblende and andesine, though biotite-andesine and hornblende-pyroxene-andesine phases are common. All three phases occur individually and grade into each other. The Byram Gneiss injects the Pochuck Gneiss in layers which range in thickness and degree of impregnation of granitic minerals. The gneissic structure is caused by three features: the orientation of mineral grains, the layering effect of the three phases, and the intimate injection by granitic Byram Gneiss.

In thin section, Fraser (1939 and 1941) found the Pochuck Gneiss to be a speckled, granulose rock with a rude, structural alignment. Other than the minerals recognized in hand specimen in the three phases, he found that the plagioclase ranged from oligoclase to labradorite and accessory minerals were apatite, magnetite, titanite and zircon. Pyroxene broke down to hornblende, plagioclase was saussuritized, and where the Pochuck Gneiss was silicified, epidotization was common.

The origin of the Pochuck Gneiss which has been the subject of much debate is not definitely determined. Spencer (1908) and others as Bayley, Kümmel and Salisbury (1914) favored a partly sedimentary, partly igneous origin. Fraser (1939 and 1941) felt that the Pochuck Gneiss had an entirely igneous origin. Although he did not rule out the possibility of a dioritic or gabbroic intrusive origin, he favored andesitic and basaltic lava flows as the original mode of formation.

Byram Gneiss

The Byram Gneiss was named from Byram Mountain in New Jersey by Spencer and others (1908). It varies in composition, texture and structure from place to place. The Byram Gneiss is a white or yellow, but more commonly, light gray, buff or brown weathering, massive to faintly foliated, fine-grained to coarse-grained, lenticular granitic rock. Foliation planes were formed by the orientation of dark minerals during flow of the consolidating magma and by partial assimilation of bands of the intruded black Pochuck Gneiss.

According to Fraser (1941) that phase of the Byram Gneiss which contains no ingested Pochuck Gneiss is composed chiefly of quartz, microcline, anorthoclase, microperthite, orthoclase and small amounts of apatite and magnetite. Darker types of the Byram Gneiss contain biotite, hornblende and plagioclase, commonly oligoclase or andesine, in addition.

The Byram Gneiss is more widely spread than the Pochuck Gneiss in Northampton (Fraser, 1939) and Lehigh (Fraser, 1941) Counties. This relationship holds in Bucks County, where the Byram Gneiss, undifferentiated on the geologic map of Bucks County (Plate 2, in pocket), is intruded into less extensive remnants of the Pochuck Gneiss. Numerous geologists (Britton, 1887; Spencer and others, 1908 and Bayley and others, 1914) observed the Byram Gneiss intruding the Pochuck Gneiss, leaving little question on the igneous origin of the former.

Pegmatites are associated widely with the Pre-Cambrian gneisses. According to Fraser (1939, p. 193) pegmatite dikes have gradational contacts with both the Pochuck and Byram Gneisses. In Bucks County, pegmatite dikes are injected into Pochuck hornblende gneiss just north of Monroe, but are most frequently in Byram Gneiss. It seems probable that the pegmatitic material was derived by differentiation from the original Byram granite. Fraser (1939) found pegmatite covered unconformably by Paleozoic sedimentary rocks and injected into Hardyston Quartzite. This indicates a long time interval between successive injections of the pegmatite. These relationships were not observed in Bucks County where the pegmatites are composed chiefly of quartz and feldspars.

Two dubious occurrences of Losee Gneiss, a name introduced by Spencer (1908) and others from New Jersey, are called Moravian Heights Gneiss by Fraser (1939, p. 189) in Northampton County, Pennsylvania. Pieces of nearly white, coarse-grained gneissic rock occur in the float in the northern ridge of Pre-Cambrian rocks in northern Bucks County. These may be Losee or Moravian Heights Gneiss, but the data are too intangible for these to be mapped as the first uncontested localities for these gneisses in Pennsylvania.

Structure

The Reading Prong in Bucks and Northampton Counties is a northeast-southwest trending belt of Cambrian and Pre-Cambrian rocks. These have been thrown into a series of complex assymetrical anticlines and synclines with fold axes parallel to the general trend. In Bucks County the north ridge underlain by Pre-Cambrian rocks forms part of the anticlinal core which extends into Northampton County and New Jersey. The southern ridge underlain by Pre-Cambrian rock between Bitts Hill and Mine Hill is the core of an irregular, long, narrow, doubly-plunging anticline almost completely surrounded by Hardyston Quartzite. The Pre-Cambrian rock underlying Rattlesnake Hill is the southwestern extremity of a long lens of metamorphosed rocks most of which lies across the Delaware River in New Jersey.

The border fault along which the core of the doubly plunging anticline is uplifted is discussed in Chapter IV (p. 140). The Durham School fault, the Bitts Hill fault and the small fault at the west corner of the Durham area are discussed in Chapter III (p. 33).

BUCKINGHAM AREA

The geologic map in U. S. Geological Survey Bulletin 828 (Bascom and other, 1931) indicates a small patch of Pre-Cambrian "gabbro" at the southwestern base of Buckingham Mountain one-half mile east of Buckingham Valley. The "gabbro" was supposed to have cropped out in a quarry shown on this map. An investigation of the quarry turned up nothing but Chickies Quartzite and conglomerate, and therefore, the "gabbro" was not shown in the geologic map of Bucks County (Plate 2, in pocket).

E. T. Wherry investigated the location of the "gabbro" in 1953 subsequent to the publication of Plate 2. About a half mile east of Buckingham Valley, two closely spaced houses, with a lane running northwestward to the western of the two, are shown on Plate 2 (in pocket). This lane turns eastward in front of the first house, runs to the second house as a gravel road, and then continues northeastward as an abandoned overgrown lane. About 100 feet east of a stone wall ruin, Wherry found "gabbro" float for 150 feet northwest of the lane in a roughly semi-circular area 200 feet in diameter. He collected a specimen of which J. D. Ryan made a petrographic study as follows:

> The rock specimen furnished by Professor Wherry as an illustrative example of "pre-Cambrian gabbro" from Buckingham Mountain is a medium-grained holocrystalline rock which on weathered surfaces is essentially black. On freshly broken surfaces, however, it is apparent that dark-colored melanocratic minerals make up only about 30-35% of the rock.
>
> In thin section, the following minerals were observed: partially sericitized feldspar (approximately 50%), hornblende (approximately 30%), quartz (approximately 15%) and magnetite, chlorite and apatite (about 5%).
>
> All of the feldspar crystals are crushed and fractured and accumulations of sericite fill the fractures. Many of the crystals and fragments have been entirely replaced by sericite. The composition of the unaltered feldspar was determined to be about An_{25} (basic oligoclase).
>
> Bright green hornblende showing good pleochroism occurs in anhedral crystal clusters of sharp outline. It is extremely fresh and unaltered. Interstitial magnetite is concentrated within and near the hornblende crystals. There is some tendency for the clusters to assume elongate form and roughly parallel each other.
>
> Highly strained and somewhat fractured elongate quartz crystals are arranged roughly parallel to the hornblende clusters. Smaller strained quartz crystals of highly irregular outline are scattered throughout the slide.
>
> Chlorite occurs in tabular plates of irregular outline throughout the rock. Some sections cut normal to cleavage contain minute flecks and stringers of brown, more highly birefringent material which presumably is biotite. Skeletal crystals of magnetite also occur within the chlorite crystals. Probably all of the chlorite is a replacement of biotite.
>
> Euhedral crystals of apatite, slightly rounded, are present as a minor accessory.
>
> This rock has the composition of a quartz diorite.

SOUTHERN AREA

The metamorphic rocks in the southern part of Bucks County are separated into two areas by the long narrow band of Chickies Quartzite (described in Chapter III, p. 50) which extends westward across Bucks County from Morrisville. The Chickies Quartzite rests unconformably on the Baltimore Gneiss north of it and is in fault contact with the Wissahickon Schist (p. 50) and Hornblende Schist south of it. All three are locally overlain by unconsolidated Quaternary sediments. Most of the area south of Chickies Quartzite is so covered.

The mappable formations (Plate 2, in pocket) in the southern area include: Franklin Limestone, Baltimore Gneiss, Metadiabase, Wissahickon Schist, Hornblende Schist, Altered ultrabasic rocks, granitized areas in Wissahickon Schist, Chickies Quartzite (described in Chapter III) and Pleistocene and Recent unconsolidated sediments (discussed in Chapter V).

Franklin Limestone

The only occurrence of Franklin Limestone is at and in the vicinity of Van Artsdalen's Quarry, Lower Southampton Township, about one mile north of Siles. Geologic investigations were made of this famous mineralogical locality by Kemp (1892), and Weiss (1947). Franklin Limestone, exposed only in and near the entrance to the quarry, is a white coarse-grained massive, locally foliated and contorted, graphitic, high-calcium limestone. It has been injected by Pre-Cambrian, dike-like bodies of gabbro which, during a plastic stage of dynamic metamorphism, were metamorphosed to metagabbro and drawn into oriented boudins (Weiss, 1947) roughly parallel to the northeast regional trend.

Bascom (1909b) correlated the Van Artsdalen marble occurrence with Franklin Limestone which crops out 70 miles to the northwest in New Jersey. Isolated as the Franklin Limestone is, its correlation and origin are necessarily vague. Weiss (1947) believed that it might have been a roof pendant in the original igneous rocks surrounding it. The Pre-Cambrian age of the Franklin Limestone is implied by the injection into it of gabbro which unconformably underlies the Cambrian Chickies Quartzite.

Baltimore Gneiss

Baltimore Gneiss occurs in a continuous belt, one half to two miles wide, north of the Langhorne belt of Chickies Quartzite and in smaller areas east and north of Morrisville, and in the vicinity of Emilie, Pennsylvania. The name, Baltimore Gneiss, was first used by Williams and Darton (1892). Mathews (1904), Knopf and Jonas (1929a) and Bascom (1909) are among the many who studied and described the Baltimore Gneiss. More recently Armstrong (1941) and Weiss (1949) studied the Baltimore Gneiss in Bucks County and westward to Bryn Mawr. Armstrong (1941, p. 673) characterized it under the title of "The Hybrid Rocks" as follows:

> Abundant field and microscopic evidence indicates that injection of felsic material into a plagioclase amphibolite (Harker, 1932, p. 311) has produced the banded and massive types of the gneiss. The character of the injection varies from magmatic intrusion of bodies with well-defined contacts to hydrothermal penetration. In some of the mixed rocks felsic and mafic bands alternate; elsewhere the injected material forms a network of dikelets in the plagioclase amphibolite, and over much of the region the mixing has been so complete that a nearly homogeneous rock has been formed. All gradations of composition occur in each mixed type. Probably both the condition of the wall rock at the time of injection and the composition of the felsic material injecting it were factors determining the character of the resulting mixed rock. The megascopically homogeneous types probably resulted where the plagioclase amphibolite was hot or the injecting material was aqueous and full of volatile constituents that facilitated permeation of the wall rock; the coarsely inhomogeneous hybrid rocks probably resulted where the wall rock was cold or the injecting magma relatively dry.

Baltimore Gneiss is a granitoid, schistose or gneissose rock ranging in composition from a granite to an amphibolite and from light gray to black depending on the amount of injected material. The principal minerals are hornblende and plagioclase, but biotite is common, pyroxene occurs locally, and, in more felsic rocks, quartz and potash feldspar appear. Accessory minerals are magnetite, epidote, zircon, pyrite and locally euhedral sphene. Alterations of original minerals are as follows according to Armstrong (1941, p. 675): pyroxene to hornblende and quartz, hornblende to biotite, plagioclase becomes more sodic (andesine to oligoclase), potash feldspar replaces plagioclase, and quartz, potash feldspar and plagioclase have replaced hornblende and biotite.

A sedimentary origin for the Baltimore Gneiss was proposed by Mathews (1904). Williams and Darton (1892) included the Pickering Gneiss with the Baltimore Gneiss and suggested that they were originally sedimentary and igneous rocks. Armstrong (1941) stated that the "mafic rocks are probably of igneous origins," but her evidence is restricted to the intrusive gabbro in the Van Artsdalen Quarry, and a lack of evidence for the development of the amphibolite by alteration of a carbonate rock. Although the mafic rocks in the Baltimore Gneiss are probably igneous in origin, this theory has not been conclusively proven.

The information presented indicates that the Baltimore Gneiss and the Byram and Pochuck Gneisses of the Reading Prong are Pre-Cambrian in age and have similar petrologic and stratigraphic relationships. They are correlated in the geologic map of Bucks County (Plate 2, in pocket).

Metadiabase

The Baltimore Gneiss is cut by a thick dike in Lower Southampton Township about two miles northwest of Trevose. The dike, trending northeast across the foliation is about 300 feet thick and is exposed 1.4 miles in Bucks County. To the southwest it continues approximately an equal distance into Montgomery County (Armstrong, 1941, Plate 1); to the northeast it is unconformably overlain by the Stockton lithofacies (Plate 2, in pocket).

Armstrong (1941, p. 683) describes this dike as one of a number of garnetiferous diorite intrusives. They are hornblende-quartz-labradorite partly subophitic rocks containing a little pyroxene and much garnet. The metadiabase dike was injected into a shear fracture in the Baltimore Gneiss after mylonization along the Cream Valley-Huntington Valley fault and was subsequently metamorphosed.

Wissahickon Schist

Wissahickon Schist is exposed in the area south of the Langhorne belt of Chickies Quartzite where Poquessing, Neshaminy, Queen Anne and Common Creeks and their tributaries have cut through the overlying Quaternary unconsolidated sediments. Bascom (1909a), McKinstry (1949), Weiss (1949) and Wyckoff (1952) described the geology and metamorphism of the Wissahickon Schist in or near Bucks County.

Wissahickon Schist is composed of mica schist, gneiss and quartzite in which the proportions of mica, quartz and feldspar vary from bed to bed. Individual layers and lenses range in thickness from about one inch to several feet. These are apparently sedimentary in origin (Weiss 1949 p. 1696) though metamorphism has developed thinner bands within the layers. The chief minerals in the Wissahickon Schist in Bucks County are quartz, plagioclase (mostly oligoclase), and micas. Common accessory minerals are garnet, staurolite, sillimanite, magnetite, apatite, zircon, sphene and ilmenite (?) flakes. Potassium feldspars have not been observed in the Wissahickon Schist of Bucks County. Tourmaline occurs as slender, black needles, which in thin section are pleochroic from pale violet or pink (X) to greenish blue or dark green (Z). In larger crystals, one millimeter in length or larger, the pleochroic formula is: (X) reddish brown, (Z) black.

Sandstone, arkose and shale, the original sediments of the Wissahickon Schist (Weiss, 1949, p. 1697), were recrystallized without addition of material by regional metamorphism which increased in intensity from northwest to southeast. Zones of metamorphism, characterized by index minerals; developed with increasing intensity toward the east and southeast. The Wissahickon Schist and related rocks (p. 18) in Bucks County are essentially in the sillimanite zone (Weiss, 1949, Wyckoff, 1952). Hydrothermal alteration of the Wissahickon Schist of Bucks County has produced sericite in cleavage cracks in plagioclase, incipient chloritization of garnet, and chloritization of biotite. Late quartz veins are also of hydrothermal origin. The tourmaline in the Wissahickon Schist is the latest mineral to have formed, and may be of hydrothermal or pneumatolytic origin.

Hornblende Schist

Two parallel lenticular areas of hornblende schist, 2.3 and 3.0 miles long, are interlayered in the Wissahickon Schist between Linconia and Neshaminy Creek. Inasmuch as the hornblende schist is mafic and has sharp contacts with the Wissahickon Schist, an intrusive origin was suggested by Weiss (1949, p. 1709). The hornblende schist is a fine- to medium-grained gneissose mafic rock in which alternate bands are mafic and felsic. The chief minerals are hornblende and andesine with a small amount of quartz. Locally residual cores of pyroxene in the horneblende suggest that the original rock had a gabbroic composition. Garnet is a rare constituent, probably because the bulk composition of the rock was not suitable for its development. Biotite, intergrown with hornblende, contains zircon surrounded by pleochroic haloes. Apatite, magnetite, sphene and epidote are common accessory minerals. Hydrothermal solutions changed a little biotite to chlorite, formed cross-cutting veinlets of calcite and locally altered plagioclase to scapolite.

Altered Ultrabasic Rocks

The following is a description of the two bodies of ultrabasic rocks in the southern area of Bucks County by Bascom and others (1909a):

> While to the southwest there are extensive areas of serpentine in the Pennsylvania Piedmont, the serpentine of the Trenton quadrangle is confined to two exposures. Two

miles south of Hulmeville, at Ford, a dike of such material occurs in the Wissahickon mica gneiss and is exposed for one-fourth mile. The rock is mottled green and gray and is now composed of tremolite, serpentine, and steatite. Calcite and magnetite are accessory constituents and by-products in the alteration of the original constituents to serpentine and talc. Serpentine is the chief constituent and is plainly secondary to the tremolite, though it is impossible to say whether all of the serpentine is of this origin. Steatite seems to be secondary both to the tremolite and to the serpentine. Tremolite has the appearance of a primary constituent, but is probably secondary to diopside or olivine. Of these constituents, however, no trace remains.

A dike of somewhat similar constitution comes to the surface for a short distance on the west side of the Neshaminy one-half mile southwest of Parkland. The rock consists chiefly of radiating crystals of yellowish-brown anthophyllite. In addition to this mineral occur calcite and steatite.

Granite Gneiss

Granite Gneiss (granitized areas in the Wissahickon Schist) has formed in two areas in Bucks County: the larger lies mostly in Philadelphia County, but extends across Poquessing Creek in Bensalem Township; the smaller, about one half mile long lies across Neshaminy Creek between Bridgewater and Croydon. This rock borders replacement granodiorite bodies which must lie below the surface at these two localities.

Structure

The major structural relationships in the southern area of Bucks County are obvious in some aspects and still questionable in others. The Franklin Limestone is an inclusion carried upward by igneous magma according to Kemp (1892) and is a roof pendant according to Weiss (1949). It is the only known occurrence of rock into which Baltimore Gneiss is injected. The body of Franklin Limestone, the foliation in it, and the boudins of meta-gabbro all trend parallel to the regional northeast-southwest trend of the enclosing Baltimore Gneiss.

The Baltimore Gneiss lying north of the Chickies Quartzite is unconformably overlain by it and by the Stockton Lithofacies. All three are unconformably overlain by Quaternary unconsolidated sediments. Foliation in the Baltimore Gneiss strikes about N.60°E. with steep dips. It is formed by the parallel orientation of hornblende grains in amphibolite, schlieren in felsic rocks and banding parallel to foliation in intermediate rock types. Although much of the foliation is secondary, the orientation in the felsic rocks is primary flow foliation (Armstrong, 1941, p. 676) controlled by the foliated amphibolite into which the felsic rocks were injected. Axes of almost all folds strike N.50°-70°E. and plunge 10°-30° NE (Armstrong, 1941, p. 676). There are two principal joint sets: one set of joints is parallel to the foliation, another strikes north and dips vertically.

The metadiabase dike in Lower Southampton Township strikes N.37° E. and dips vertically. The dike was injected after mylonization along the Cream Valley-Huntingdon Valley fault but probably before Paleozoic sediments were deposited (Armstrong, 1941, p. 688).

Inasmuch as the hornblende schist, ultrabasic rocks and granite gneiss are integral parts of the Wissahickon Schist, their structures are identical or similar and are considered as a unit. The Wissahickon Schist is in fault contact with Chickies Quartzite on the north, possibly with Baltimore Gneiss on south, and is unconformably overlain by Quarternary unconsolidated sediments. Foliation is parallel to bedding, in the Wissahickon Schist, which because of degree of metamorphism, lack of fossils and traceable beds cannot be correlated. The regional strike of the foliation is northeast-southwest. Dips, alternately steep and gentle both southeast and northwest, may indicate two limbs of overturned folds (Weiss, 1949, p. 1791).

Most of the folding is flexural-slip folding in which competent layers respond to compression by bending, and incompetent layers by slipping along bedding planes. The amplitudes of observed folds range from an inch to about 100 feet, although changes in dip may indicate larger folds. Weiss (1949, p. 1721) plotted on a Schmidt net the poles of 85 axial planes of folds in the sillimanite zone, which includes the southern area. A maximum indicates that most folds are overturned to the southeast. A strong lineation in the foliation planes is parallel to axial planes of folds. A plot of these lineations shows that the average regional plunge in the sillimanite zone is 16° NE. Drag folds, more common in the micaceous layers, are similar to and have axial planes parallel to larger folds. They reliably indicate direction to anticlinal crests.

Most joints have steep to vertical dips and strike perpendicular to fold axes. Locally joints are parallel to the foliation.

The Cream Valley-Huntingdon Valley fault (Bascom, 1909b) which separates Wissahickon Schist from Chickies Quartzite is shown on Plate 2 (in pocket) as a thrust fault, and described as a high angle reverse fault (Weiss, 1949, p. 1723). This deduction is based on numerous small drag folds along the fault which show movement upward to the north with the Wissahickon Schist moving up relative to the Chickies Quartzite (Weiss, 1949, p. 1722). Armstrong (1941, p. 684) also observed drag folds that show movement in both directions indicating that there has been more than one period of slipping along the fault and the downthrown side has not always been the same. The evidence for direction of movement along the fault based on drag folds is not conclusive and other criteria should be considered.

The presence of Baltimore Gneiss in the vicinity of Emilie and east of Morrisville along the Delaware River is anomalous. East of Emilie the Baltimore Gneiss is shown (plate 2, in pocket) in contact with a small lens of Wissahickon Schist. Data are based almost entirely on float. Along the Delaware River, the Baltimore Gneiss was not observed in contact with any other formation. The two areas are roughly in line. Inasmuch as Wissahickon Schist does not directly overlie Baltimore Gneiss (McKinstry, 1947), stratigraphic requirements suggest the interposition of a fault. It is indicated as a thrust fault (?) with Baltimore Gneiss upthrown against Wissahickon Schist.

Numerous faults too small to show in a map of this scale (Plate 2, in pocket) were observed in the field.

AGE OF METAMORPHISM

The pre-Triassic rocks of Bucks County have all undergone at least one metamorphism, and there are indications, though not proofs, of more than one. Franklin Limestone was injected by gabbro with little or no contact metamorphism (Weiss, 1949, p. 831). Gabbro of the Pochuck Gneiss and Baltimore Gneiss were injected by felsic material and hydrothermal solutions with some contact action. After injection of the metadiabase dike, Franklin Limestone and Pochuck, Byram and Baltimore Gneisses were dynamically metamorphosed during Pre-Cambrian time.

The age of the Wissahickon Schist, either Pre-Cambrian or early Paleozoic, has been in question for some time (Bliss and Jonas, 1916; Knopf and Jonas, 1929; Hawkins, A. C., 1924; Mackin, 1935; Cloos and Hietanen, 1941; McKinstry, 1949). If it is Pre-Cambrian, it was metamorphosed with rocks of definite Pre-Cambrian age. If it is early Paleozoic, for which there is almost a consensus of opinion, it was metamorphosed possibly during the Taconic disturbance (Willard and Cleaves, 1939) and definitely during the Appalachian revolution. Hornblende schist, ultrabasic rocks and granite gneiss, as phases of or intrusives into Wissahickon Schist, shared its metamorphism, whatever its age.[2]

If the Wissahickon Schist is Paleozoic in age, it would be down-faulted rather than overthrust against Chickies Quartzite. Proof for either proposal has not been conclusive.

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[2] The early Paleozoic age of the Glenarm Series which includes the Wissahickon Schist is further established by Wasserburg, Pettijohn and Lipson (1957). See bibliography.

Chapter III

PALEOZOIC SEDIMENTARY ROCKS

by

Bradford Willard

General Statement

Paleozoic sedimentary rocks are exposed in three areas of Bucks County: Durham, Buckingham and Langhorne, from north to south. There are similarities and differences among the formations of the three areas; no two have the same stratigraphic succession. Each will be described as a unit, and then the three compared and contrasted as a whole. The location of the three areas is shown in Figure 1 (p. 24).

Durham Area

General Statement

The northernmost of the three patches of Paleozoic sedimentary rocks in Bucks County occupies the valley of Durham (Cook) Creek close to the northeastern boundary. To the northwest along the Northampton-Bucks County line rises a steep ridge of Pre-Cambrian gneisses (Chapter II, p. 13). South of the Durham (Cook) Creek Valley, another ridge of Pre-Cambrian gneisses separates most of the Paleozoic rocks from the main body of Triassic rocks. It is in part the extension into Pennsylvania of Musconetcong Mountain of New Jersey. Extensions of the Lower Cambrian quartzite and some small, isolated patches of Cambrian limestone among the southern hills are included in the Durham area.

Durham (Cook) Creek Valley is roughly triangular with its base two miles long on the Delaware River at Riegelsville, and its apex at the edge of Leithsville, northwest of the Bucks County line. The total area in Bucks County between the two border ridges is approximately seven square miles.

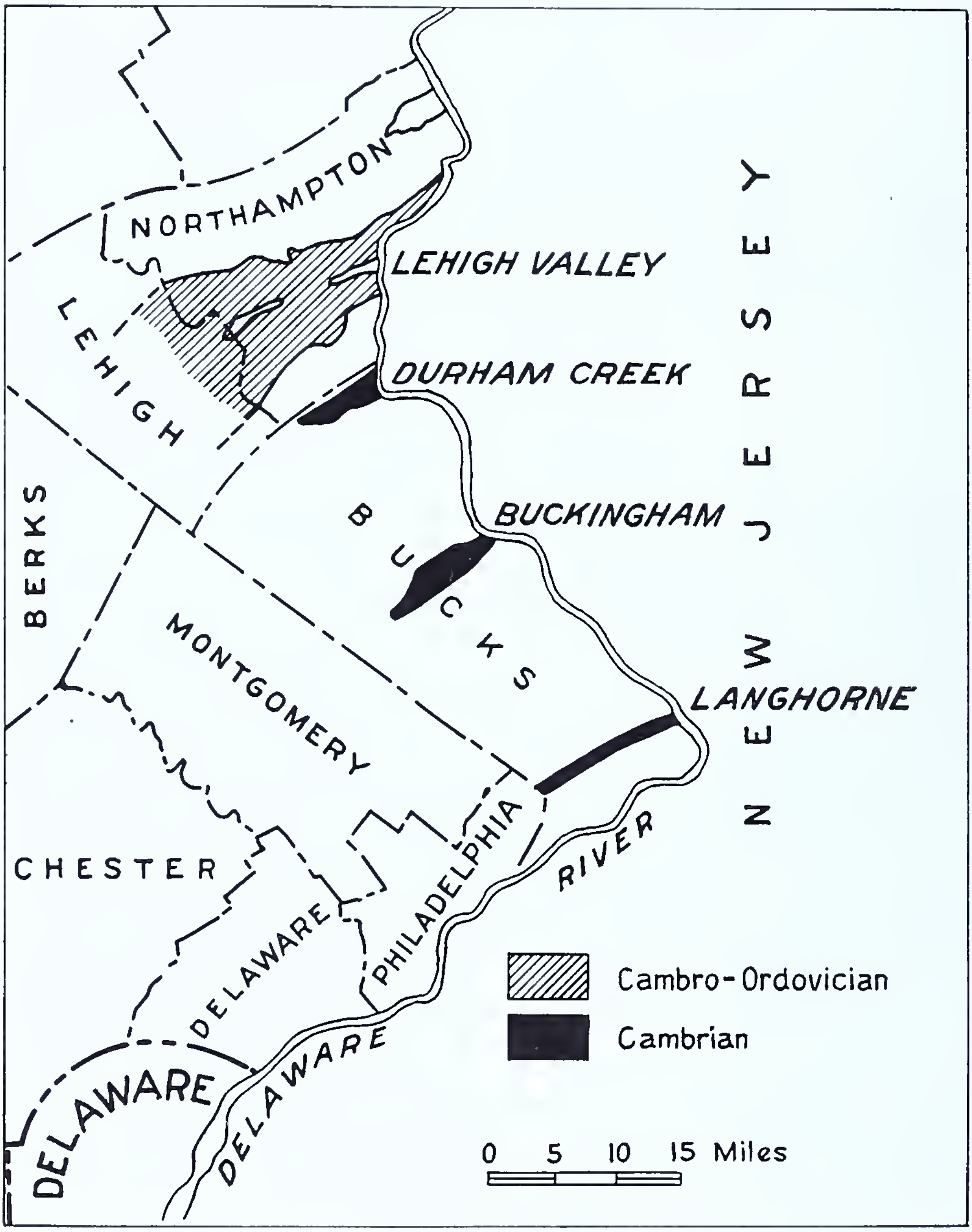
All the Paleozoic sedimentary rocks in Durham (Cook) Creek Valley are assignable to the Cambrian system and resemble the Lehigh Valley sequence to the north and that of New Jersey to the east.

The Paleozoic sedimentary formations in the Durham area are Hardyston Quartzite and Cambrian limestones. Howell, Roberts and Willard (1950) subdivided the Cambrian limestone (Table 2, p. 9) as follows:

Allentown Limestone
Limeport Limestone
Leithsville Limestone

The boundary between the Leithsville Limestone and the Limeport Limestone is gradational and occurrences of the Limeport and Allentown Limestones, though identifiable in quarries, cannot be separated. These formations are mappable elsewhere but were treated as a unit called Cambrian limestones in the Durham area and on Plate 2 (in pocket).

FIGURE 1



Sketch map of Bucks County to show Paleozoic areas.

"Tomstown" dolomite, which may be correlated with the Leithsville Limestone (Howell, Roberts and Willard, 1950), is locally differentiated in narrow belts along the Triassic border fault.[3]

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[3] Subsequent to the publication of the Bucks County Geologic Map (Plate 2), Howell, Roberts and Willard (1950) and Willard (1955) showed that the name Tomstown as used by Miller in Northampton and Lehigh Counties (1939 and 1941) was inappropriate. They revived Wherry's (1909) name Leithsville for this, the lowest of the dolomitic limestones. Further, they broke down Miller's Allentown (Upper Cambrian) into Limeport below and restricted Allentown to the upper part. Willard (1955) published sketch maps showing distribution of some of these formations.

Stratigraphy

The stratigraphy of the Durham area embraces the Hardyston Quartzite and the Cambrian limestones of which the Tomstown Dolomite is locally differentiated (p. 24). All are assigned to the Cambrian.

Hardyston Quartzite

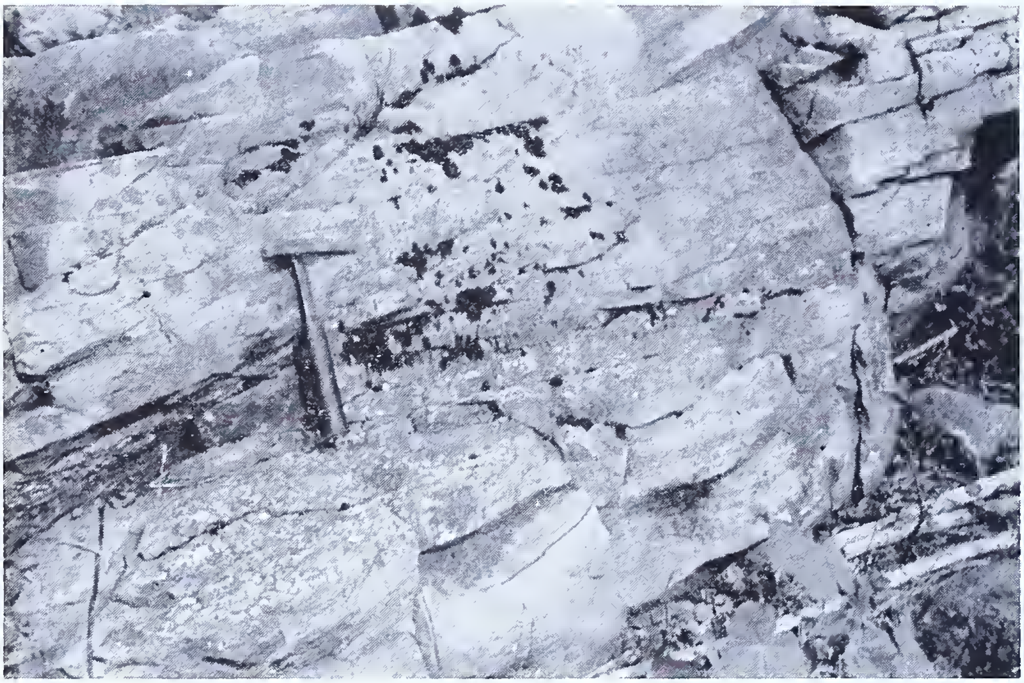
The Hardyston Quartzite is the oldest sedimentary rock in the Durham (Cook) Creek Valley. Originally named Hardystonville by J. E. Wolff and A. H. Brooks (1898) for the village in northern New Jersey, the name was abbreviated to Hardyston by Stewart Weller (1903). In the type area it is predominantly quartzite, but includes limestone, shale, and scattered conglomerate. It is significant that the conglomerate is not confined to the lower part, inasmuch as lack of a well-defined "basal conglomerate" gives preference to the name Hardyston rather than Chickies (p. 38). The typical Chickies Quartzite includes a distinct, conglomeratic basal member, the Hellam Conglomerate. The early Cambrian age of the Hardyston Quartzite in New Jersey has been established by Weller on the presence of *Olenellus* (1903, p. 10).

The Hardyston Quartzite which fringes the bases of the gneissic hills of the north side of Durham (Cook) Creek Valley, dips toward the valley as a continuous band except where offset by faulting. It reappears along the south side, and fingers southward around some of the smaller hills into the valley west of Monroe and the heights south of Springtown. As noted above (Chapter II, p. 13), one small exposure of quartzite and gneiss was discovered in the midst of the Cambrian limestones a mile west of the summit of Bitts Hill. Its relationship to the Cambrian limestones is undetermined. Because outcrops are so few much of the mapping of the Hardyston Quartzite is based on float. In general, its base on the hills has been drawn at the highest observed quartzite float. Because of this assumption, the band of Hardyston Quartzite is generally wider than that mapped by Bayley (1941).

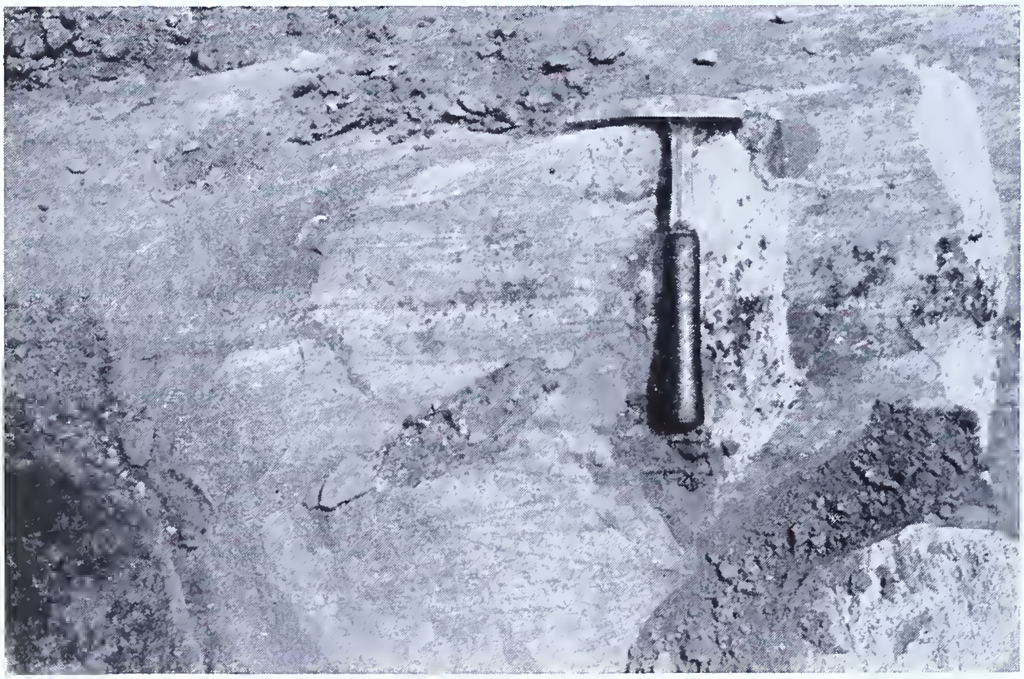
The lithology of the Hardyston Quartzite varies considerably (Plate 4, p. 26), but the formation is best described as resistant, blue-gray quartzite, so dense that it commonly develops conchoidal fracture surfaces. Local textural variations range from white, yellow and red jasper, with drusy vugs, to conglomerate with pebbles up to two inches in diameter. Several pits in jaspery Hardyston Quartzite were dug by prehistoric Indians who fashioned weapons and tools from it. Conglomerate is locally found near the base, but may be absent there and appear as recurrent, higher bands. Some beds, less firmly cemented, are quartz sandstone; many are arkosic. Weathered, arkosic quartzite is difficult to distinguish from weathered acid phases of the Pre-Cambrian gneiss. Bedding is usually graded and fairly uniform, ranging from six to twelve inches in thickness. Neither cross-bedding nor ripple marks are common (Plate 4B).

The thickness of the Hardyston Quartzite probably nowhere exceeds 300 feet in Durham (Cook) Creek Valley, but may be locally only a few tens of feet. The only section to show approximately both top and bottom contacts is along the River Road (U. S. Highway 611)

Plate 4



A. Hardyston Quartzite east of Springtown showing interbedded conglomeratic band. Photo by B. L. Miller.



B. Detail of Hardyston Quartzite southeast slope of Mine Hill showing cross-bedding. Photo by B. L. Miller.

south of its intersection with Pennsylvania State Route 212 below Durham Furnace. Here only 67 feet were measured, but obscure slip faulting may have reduced the thickness. In Northampton County the thickness of the Hardyston Quartzite is said to range between 25 and 325 feet (Miller, 1939, p. 214), while in New Jersey the State Survey estimates the maximum at 200 feet (Lewis and Kümmel, 1940, p. 66).

No fossils other than doubtful *Scolithus* are known from the Hardyston Quartzite in northern Bucks County. In New Jersey, Weller (1903) reported *Olenellus thompsoni* from weathered limestone beds, which are lacking in Bucks County. However, there is no doubt of the correlation of the Hardyston Quartzite in the Durham area and in Northampton County with that in New Jersey.

The lower contact of the Hardyston Quartzite can be identified if the gneiss and quartzite are not severely weathered. It is exposed in the following localities: on the Delaware River road below Durham Furnace; at a bend in the north-south road two miles east of Springtown; and on the north side of Durham Creek Valley at an elevation of 380 feet. Another contact, probably faulted, may be observed in the open country a mile west of the summit of Bitts Hill, where a small quarry exposes gneiss and pebbly Hardyston Quartzite. This is one of the few places where the lower part of the Hardyston Quartzite is known to be conglomeratic. Half a mile southwest of the crest of Mine Hill, another exposure contains conglomerate of white quartz pebbles up to two inches in diameter, which are subangular, and embedded in a dark-gray, friable quartzitic matrix, suggestive of graywacke. Its precise relations to other formations are obscure. Although it is unlike any known Triassic conglomerate in the northern part of Bucks County, it resembles the pebbly Stockton Lithofacies to the south. During low water in the brook valley west of Durham Union Church, a firmly welded gneiss-quartzite contact was observed. West of the river road north of Riegelsville the contact could not be precisely drawn, although both gneiss and quartzite were identified. In New Jersey, a similar situation was met eastward along the strike. In the Delaware River at low water the contact is well-exposed south of Riegelsville, New Jersey, opposite Durham. Springs are commonly found at the quartzite-gneiss contact such as at the camp meeting grounds east of Springtown and in the region northwest of Riegelsville.

The one exposure found of the upper contact of the Hardyston Quartzite is poor. It is in a small cut along the River Road (U. S. Highway 611) below Durham Furnace. The quartzite is overlain by highly sheared, shaly, Tomstown Dolomite (Leithsville Limestone). The contact is probably faulted. Recently, Whitcomb (1948) described a disconformity between the Hardyston Quartzite and Tomstown Dolomite (Leithsville Limestone) near Hellertown in Northampton County, three miles northwest of the western end of Durham (Cook) Creek Valley.

B. L. Miller (1939, p. 215, and 1941, p. 173) reported that no upper contact of the Hardyston Quartzite had been observed in either Lehigh or Northampton Counties. Since then two contacts have been turned up in Northampton County. The first is along U. S. Highway 611, half a mile north of Raubsville, and the second, a more doubtful contact, in an abandoned limestone quarry at Redington. The relations indicate conditions similar to that described above for the section on the River where the upper part of the Hardyston Quartzite grades through thirty feet of shaly beds into the base of the Cambrian Tomstown Dolomite (Leithsville Limestone).

Cambrian Limestones

The Cambrian limestones in the Durham area include Tomstown Dolomite (Leithsville Limestone), Limeport and Allentown Limestones (p. 23) of Howell, Roberts and Willard (1950). Table 4 is a correlation of the formation names used in the literature for the Durham, Buckingham and Langhorne areas.

TABLE 4. *Correlation of the Cambrian Formations in Bucks County, Pa.*

Durham Area	*Buckingham Area*	*Langhorne Area*
Conococheaque (Allentown) Limestone	Conococheaque	
(Limeport) Limestone	(Limeport) Limestone	
Tomstown Dolomite (Leithsville Limestone)	Elbrook (?) (Leithsville) (Limestone	
Hardyston Quartzite	Chickies Quartzite Hellam Conglomerate	Chickies Quartzite Hellam Conglomerate

Tomstown Dolomite (Leithsville Limestone)

The type locality of the Tomstown Dolomite is in Franklin County, Pennsylvania (Stose, 1906). Its lithology differs from that of the Leithsville Limestone, and it is thinner than the Tomstown Dolomite of Lehigh Valley. It rests upon the Antietam Sandstone which overlies Chickies Quartzite, a correlative of the Hardyston Quartzite. The typical Tomstown Dolomite is overlain by the Elbrook Limestone which separates it from the Conococheague Limestone. The age of the Tomstown Dolomite is stated to be early or middle Cambrian. Direct correlation with the type locality has not been established.

The only part of the Cambrian limestones that have been differentiated as "Tomstown Dolomite" on the geologic map of Bucks County (Plate 2, in pocket) consists of two narrow east-west strips. The first is in a valley southwest of Monroe. Hardyston quartzite (?) is exposed in the brook, in an abandoned quarry south of the road and westward along the valley. On the hill slope or bluff behind the village houses, Tomstown Dolomite is poorly exposed between the Hardyston Quartzite to the north and the Triassic limestone conglomerate and red beds which crop out along U. S. Highway 611 to the south. This sliver of Tomstown Dolomite can be traced along a few outcrops westward up the valley for six-tenths of a mile. The westernmost sign of the formation is at some springs where the road turns northwest. Here a local resident encountered dolomite in cleaning out the springs. The rock is not now exposed.

Although the Monroe slice of Tomstown Dolomite ends at the springs, the rock reappears along the strike as a second slice in a brook valley a mile west of Franklin School. It was traced up this valley and along the depression south of the road toward West Springfield School for approximately one and three-fourths miles. The Tomstown Dolomite rests against the Hardyston Quartzite to its north. Along its south border the Tomstown Dolomite is brecciated and in contact with Triassic limestone conglomerate. It is difficult to distinguish the Tomstown Dolomite from the Triassic limestone conglomerate.

On U. S. Highway 611 midway between Durham Furnace and Monroe a small, steep-sided valley descends to the river. At road level, a small outcrop of limestone, presumably Leithsville ("Tomstown") is exposed among outcrops of Pre-Cambrian gneisses. The entire outcrop of limestone occupies hardly more than 100 square feet. No Hardyston was found in place, and the limestone-gneiss relations are obscure. It is of historical significance that Henry D. Rogers in his 1858 "Geology of Pennsylvania" showed this limestone outcrop in his river section (p. 98, fig. 3).

The name Leithsville was introduced by E. T. Wherry (1909, p. 416) to include "1500 feet" of gray dolomite with many sandy and cherty layers and buff shale beds. He placed it between his Allentown Limestone and the Hardyston Quartzite and assigned it to the Middle and Lower Cambrian. This name is taken from the village of Leithsville, Northampton County, at the head of the Durham (Cook) Creek syncline. It appears to coincide with the Tomstown Dolomite of the Lehigh and Northampton County reports of Miller (1939 and 1941). Wherry's name Leithsville Limestone has been used to embrace all the Cambrian limestone between the Hardyston Quartzite below and the overlying Conococheague (Limeport) Limestone (Howell, Roberts and Willard, 1950).

The distribution of the Tomstown Dolomite (Leithsville Limestone) cannot be shown on the geologic map except for the locally differentiated slices. It has not been differentiated satisfactorily from the overlying Conococheague (Limeport) Limestone because most of the exposures are in isolated quarries. Normally, there should be a band of Tomstown Dolomite (Leithsville Limestone) bordering the Hardyston Quartzite along the inner side of the synclinal valley. Exposures are too scattered to permit continuous mapping. South of Riegelsville in the vicinity of Durham Furnace, it is exposed on the River Road (U. S. Route 611) immediately south of the intersection with State Highway 212. At Durham Cave two-tenths of a mile north, and in small, ancient quarries a half mile northwest of the intersection are exposures of Tomstown Dolomite (Leithsville Limestone). The formation was not positively recognized to the west along the south side of the valley. Northwest from Riegelsville, Pennsylvania, small, long-abandoned quarries expose Tomstown Dolomite (Leithsville Limestone) along the foot of Bougher Hill in Bucks County. It was recognized south of Durham Union Church. Farther west, the last unquestioned exposure of Tomstown Dolomite (Leithsville Limestone) along the north side of the valley is in the vicinity of an ochre pit a mile and a quarter east-northeast of Springtown. On the geologic map of Northampton County (1939), Tomstown Dolomite underlies the upper end of Durham (Cook)

Creek Valley east of Leithsville. The southern and northern bands of Tomstown Dolomite (Leithsville Limestone) probably merge in the synclinal nose at the valley head. Eight hundred feet, which is believed to be a reasonable thickness for Tomstown Dolomite (Leithsville Limestone), is more than the 600 feet reported by Miller for eastern Northampton County at Morgan Hill (1939, p. 226) and less than that at the type locality.

The lithology of the formation is variable. In many beds, it is a blue-gray to yellowish-white rock which weathers buff or chalky. Bedding fluctuates from massive strata up to ten feet thick, through platy to shaly, sericitic layers, which weather into shiny fragments scattered through the residual soil. These sericitic beds and the rhythmic change from massive through platy to shaly bedding are the most distinctive properties of Tomstown Dolomite (Leithsville Limestone). The cycles can be observed only in fairly large exposures. The following section of an abandoned quarry two-tenths of a mile east of Durham School along the north side of Durham (Cook) Creek shows the lithology of the formation in typical repetitious sequence:

	Feet
Shale and shaly, dolomitic limestone	7
Massive, dolomitic limestone	5
Shaly, dolomitic limestone and shale	1
Massive, blue, dolomitic limestone	4
Shale and shaly, dolomitic limestone	5
Massive, dolomitic limestone	4
Shaly, dolomitic limestone	5

Unlike the overlying Conococheague (Limeport and Allentown) Limestone, the Tomstown Dolomite (Leithsville Limestone) has few sandy beds and oölites. Edgewise conglomerate, ripple marks, and mud-cracked shale has been observed.

The chemical composition of the Tomstown Dolomite (Leithsville Limestone), like the other Cambrian and older Ordovician carbonate rocks of eastern Pennsylvania, is indicated in Table 5 (Miller, 1934).

TABLE 5. *Chemical analyses of Tomstown Dolomite (Leithsville Limestone)*

	1	*2*	*3*	*4*	*5*
CaO			31.95	30.52	29.96
MgO			18.05	19.71	18.66
Al_2O_3	0.58	2.20	2.62	2.30	4.60
Fe_2O_3					
SiO_2	1.90	4.77	2.70	2.30	4.60
S	.02			tr	tr
P	tr			tr	tr
$CaCO_3$	52.16	53.43		54.50	53.50
$MgCO_3$	43.28	41.43		41.39	39.18
	97.94	101.83	55.32	100.49	97.88

Number 1, quarry at Island Park, south side of Lehigh River; number 2, Redington quarry of Bethlehem Steel Company at Redington; number 3, O. E. Leh quarry at Redington; 4 and 5, are samples from Durham Cave near Riegelsville, Bucks County.

Since dolomite is a double carbonate of calcium and magnesium, $CaMg(CO_3)_2$, in which the proportion of the two carbonates is $CaCO_3$ 54.35% to $MgCO_3$ 45.65%, the rock may be close to true dolomite.

The lower contact of the Tomstown Dolomite (Leithsville Limestone) with the underlying Hardyston Quartzite is discussed above (p. 27). No sharp upper contact between Tomstown Dolomite (Leithsville Limestone) and Conococheague (Limeport and Allentown) Limestone has been reported from the Lehigh Valley (Miller, 1939, p. 227, 1941, p. 184), where it is said to be transitional. In northern Bucks County the contact was not found. It is the writer's opinion that the two formations are conformable. Wherry drew the base of the Allentown Limestone below the lowest *"Cryptozoa."* Although this practice was followed by Miller (1939, 1941), Hills (1935) drew it somewhat higher. The lithology seems to agree with the concept of Wherry and Miller, rather than Hills whose boundary appears arbitrary in his published section. The Conococheague (Limeport) Limestone contains identifiable algae which separates it from barren Tomstown Dolomite (Leithsville Limestone).

There is no direct evidence as to the age of the Tomstown Dolomite (Leithsville Limestone) in Bucks County. No fossils save doubtful algae have been found in it in eastern Pennsylvania. The best that can be said of the age of Tomstown Dolomite (Leithsville Limestone) is that it may conformably overlie Hardyston Quartzite which is early Cambrian; it is succeeded by the Conococheague (Limeport) Limestone which is early late Cambrian with no proof or disproof of middle Cambrian in northeastern Pennsylvania. Thus, the age of the Tomstown Dolomite (Leithsville Limestone) may be early or middle Cambrian, both or even very early, late Cambrian.

Conococheague (Limeport and Allentown) Limestone

Recent work in Bucks County and the Lehigh Valley by Howell, Roberts and Willard (1950) and by Howell on the Cambrian in New Jersey (1945) has shown that the Allentown Limestone, named by Wherry (1909) for the city of Allentown, Pennsylvania, is divisible into two formations, the upper Allentown and lower Limeport Limestones. Inasmuch as the Limeport and Allentown Limestones were not mapped separately in Bucks County, correlation with the Conococheague Limestone as suggested by Miller (1934) is arbitrarily adopted in this report (Table 4, p. 28).

The Conococheague (Allentown and Limeport) Limestone lies in the axial portion of the Durham (Cook) Creek syncline. Exposures may be seen on the New Jersey side of Delaware River opposite Riegelsville, Pennsylvania, and in scattered, abandoned quarries in Pennsylvania. Along Durham (Cook) Creek between Riegelsville and Durham Furnace, large quarries formerly supplied Conococheague (Allentown and Limeport) Limestone as flux to the iron furnaces. Intermittent showings, chiefly quarries, continue westward along the south side of the Durham (Cook) Creek Valley. All limestone identified at or near the axis of the syncline, which should be the youngest in the sequence, is Conococheague (Limeport-Allentown) Limestone.

Lithologically, the older Conococheague (Limeport) Limestone is similar to and somewhat intermediate between the younger Conococheague (Allentown) Limestone and older Tomstown Dolomite (Leithsville

Limestone). The alternation of dark and light beds, and the blue-gray massive dolomite so characteristic of the Conococheague (Limeport) Limestone, is less obvious, the bedding, thicker and more irregular. Chemically, the Conococheague (Limeport and Allentown) Limestone approaches a true dolomite. It is high in SiO_2 from the occurrence of interbedded quartz sand and scattered quartz grains. The strata range from six inches to two feet in thickness. Shale, ripple marks, mud cracks, oölite, and intraformational conglomerate or breccia occur sparingly in the Conococheague (Allentown) Limestone and more commonly in the Conococheague (Limeport) Limestone. The algae, the only organic remains identified from Conococheague (Allentown) Limestone in the Durham (Cook) Valley, are common and easily recognized. Both they and the oölites are more readily discerned on weathered than fresh surfaces. Quartzitic sandy beds and sericitic shale occur, particularly in the lower strata.

The following chemical analyses (Miller, 1934) indicate somewhat variable compositions in the Conococheague (Limeport and Allentown) Limestone.

TABLE 6. *Chemical Analyses of Conococheague (Limeport and Allentown) Limestone in the Durham Area*

	1	*2*	*3*	*4*	*5*	*6*	*7*
CaO	27.15	35.21	25.45	27.62	28.85	31.49	28.43
MgO						14.83	20.87
Al_2O_3	1.83	1.32	2.35	1.68	1.80	2.75	1.13
Fe_2O_3	1.06	1.03	1.46	.86	1.10	2.01	1.00
SiO_2	8.65	7.99	13.65	8.84	9.49	7.01	4.43
$K_2O + Na_2O$	.36		2.48				
P	tr	tr	tr	.03	.01	tr	.02
S			tr	.02	.01	tr	.09
$CaCO_3$	48.48	62.88	45.45	49.32	51.53	56.23	50.76
$MgCO_3$	39.86	25.72	34.32	39.37	34.83	31.20	48.82

All of the analyses are from the abandoned flux quarries in the vicinity of Durham Furnace. Numbers 1-6 are from the Conococheague (Limeport) Limestone, number 7 from the Conococheague (Allentown) Limestone.

The thickness of upper Conococheague (Allentown) Limestone is estimated as between 200 and 400 feet and of lower Conococheague (Limeport) Limestone as 500 feet. This takes into account that the basal contact is not sharply defined, and, inasmuch as no Beekmantown Limestone has been found in the Riegelsville area, that the highest beds of the Conococheague (Allentown) Limestone are probably missing also.

The Dresbachian age of the lower Conococheague (Limeport) Limestone is established on the presence of inverterbrate fossils in central Bucks County and at Carpentersville, New Jersey, and by the calcareous algae associated with these invertebrates and found also in Durham (Cook) Valley. Thus, its age is early, late Cambrian.

The late, late Cambrian or Trempealeauian age of the Allentown Limestone has been determined from the occurrence at Portland, Pennsylvania, of Trempealeauian invertebrate fossils identified by Howell (1945). Associated with these are algae which can also be recognized in Bucks County and have been so identified by Roberts (Howell, et al. 1950).

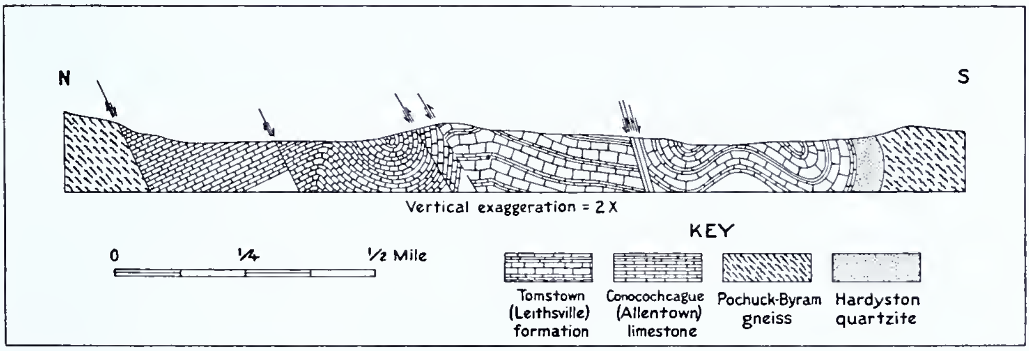
Structure

The major structure of the Durham area consists of two doubly-plunging anticlines, with Pre-Cambrian cores and a syncline between underlain by Cambrian rocks. The northern of the two anticlines lies half in Bucks County and half in Northampton County. A border fault separates this portion of the Reading Prong from the Triassic rocks to the south and southwest. Four major and innumerable minor faults dissect the Durham area.

The outlines of the anticlinal cores are complicated by minor folds but Hardyston Quartzite wrapping around both ends of the anticlines is proof that they are doubly plunging, with their axes striking about N. 60° E. The synclinal axis appears to be horizontal, however, minor folds plunge westward in keeping with data further south that post-Ordovician folds plunge southwestward (Armstrong, 1941). The Cambrian limestones have been intricately folded and faulted (Figure 2, p. 33) and at least two synclines have been recognized.

The abandoned quarries and a few small, natural exposures of Cambrian limestone along Durham (Cook) Creek at the large meander a mile east of Durham Church have supplied significant data. Stromatolites, crossbedded and ripple marked sandstones and mud cracks afford ready means for determining tops of beds. The south limb of a syncline is indicated in the most northerly of the quarries where the beds strike N. 55° E. and dip 85° N. The north limb of this fold may be seen in an abandoned quarry at the town line along the west boundary of Riegelsville. Continuing southeastward, a prominent brecciated zone shows along the road. At the next quarry the beds dip 25° S. on the north limb of the second syncline. The south limb appears immediately to the south with a 60° N. dip indicating an asymmetrical fold. It is believed that the northern syncline corresponds to that shown by Beeler and Chow in the Upper Cambrian beds in the northern part of their section (Fig. 2, p. 33) and the southern syncline may partly equal that in the southern part of their section. Where they show two faults, one was recognized along Durham (Cook) Creek, and there is an indication of the second in the vicinity of Durham Cave between Durham (Cook) Creek and the Delaware River.

FIGURE 2


N
S
Vertical exaggeration = 2X
KEY
0
1/4
1/2 Mile
Tomstown (Leithsville) formation
Conococheague (Allentown) limestone
Pochuck-Byram gneiss
Hardyston quartzite

North-south section through Riegelsville, New Jersey, prepared by D. O. Beeler and M. M. Chow.

A prominent cross-fracture, the Durham Union Church fault, crosses the valley from north to south through Durham Union Church. This is a tear or strike-slip fault along which the east side has moved south relative to the west side. Hardyston Quartzite may be seen in contact with Pre-Cambrian gneiss as one ascends Steelys Hill in the vicinity of Durham Union Church and the cemetery. Tomstown Dolomite (Leithsville Limestone) was noted nearly in contact with exposures of Conococheague (Allentown or Limeport) Limestone in quarries east of Durham School, and about one-half mile west of Durham School and in the small valley to the west of the road. Along the brook in this valley the displacement of the Hardyston Quartzite and the Pre-Cambrian gneisses is apparent, yet nowhere was the actual fault surface seen.

The Durham Union Church fault was not observed in the Cambrian limestones under the alluvium bordering Durham (Cook) Creek. However, in the hills south of the valley, there is an offset of the gneiss and quartzite which aligns with the strike of the fault in the vicinity of Durham Union Church.

East of Springtown a narrow quartzite ridge extends for three-quarters of a mile southwestward into the Cambrian limestone valley. The rock can be seen where Pennsylvania State Route 212 turns southeast at a mill pond, and boulders and ledges of quartzite are half-hidden among the trees which cover the ridge. Quarries in Conococheague (Allentown or Limeport) Limestone were once worked between the northwest side of the ridge and the east edge of Springtown. No underlying Tomstown Dolomite (Leithsville Limestone) was found. The ridge is interpreted as a narrow Hardyston Quartzite wedge faulted up across the valley. The southeastern contact was not seen, nor was there any indication of the fault's continuation across the valley in Bitts Hill.

A small fault runs northwest between the two crests of Bitts Hill where Hardyston Quartzite is offset from Pre-Cambrian gneiss and Cambrian dolomite. It is apparently a tear or strike-slip fault along which the northeast side has moved northwest.

A mile west of the crest of Bitts Hill, along a secondary north-south road, in the Cambrian limestone valley, a small, abandoned quarry exposes conglomeratic beds in the Hardyston Quartzite. Gneiss float may be found nearby, particularly eastward across the road. A quarter of a mile southeast of the quarry along a small north-flowing brook, north of a "Walking Purchase" monument, the Cambrian limestone in the stream bed is brecciated. Whether the Hardyston Quartzite in the quarry and the brecciated Cambrian limestone are in fault contact is not known. It is assumed that the Hardyston Quartzite and Pre-Cambrian gneiss are upfaulted by a minor dislocation in Cambrian limestones.

There are doubtless other, less well-authenticated faults in the Durham area. Probably one runs between Mine and Rattlesnake Hills to offset the Hardyston Quartzite. Evidence is poor and it is not shown on the map. Other small faults probably border Rattlesnake Hill on the north and northeast and dissect the Cambrian limestones. Slipping along the Cambrian-Pre-Cambrian contact has been observed in many places in Northampton County (Fraser, 1939). Although specific exposures showing this relationship have not been observed in Bucks County, movement along the Cambrian-Pre-Cambrian contact probably occurred. The border fault between the Triassic and Paleozoic rocks is analyzed in Chapter IV. Local folding of great complexity is inferred from some of the quarry holes in the Cambrian limestones.

The age of folding and faulting in the Durham area can be deduced. Presumably, the area underwent two major intervals of compression, one during the Taconic disturbance near the end of the Ordovician period and the other during the Appalachian revolution at the close of the Paleozoic era. Evidence of two stages of compression was not obtained. They are postulated in Bucks County because of having been demonstrated among higher Paleozoic rocks of northeastern Pennsylvania (Behre, 1933b, p. 171 & Miller 1926, etc.).

BUCKINGHAM AREA

The Buckingham area extends across east-central Bucks County (Plate 2, in pocket and Figure 1, p. 24). From a point one and three-fourths miles southeast of Doylestown, it trends northeastward to the Delaware River at Limeport. The Buckingham area is roughly elliptical, ten miles long, in a N. 40° E. direction, two miles wide at its maximum, and includes about twelve square miles. Along the southwestern half rise the Chickies Quartzite ridges, Buckingham and Little Buckingham Mountains.

The Buckingham area has been studied by the U. S. Geological Survey (Bascom and others, 1931) in that part of the Buckingham area in the Doylestown quadrangle west of Aquetong village. The geological mapping to the east was published in the Trenton Folio (Bascom and others, 1909b) on a scale of 1/125,000, with the Paleozoic limestones mapped as a single unit, the Shenandoah Limestone. In Bulletin 828 (Bascom & others, 1931), mapped on a scale of 1/62,500, three divisions are recognized: Elbrook, Conococheague and Beekmantown Limestones. Inasmuch as it has been differentiated, the name, Shenandoah Limestone, is dropped.

Correlation of Elbrook (?) (Leithsville) and Conococheague Limestones in Bucks County with the same formations in Franklin County (Stose, 1906) is questionable. Although Howell, Roberts and Willard (1950) suggested the use of Leithville and Limeport Limestones respectively (p. 43), Elbrook (?) (Leithsville) and Conochocheague (Limeport) Limestones are retained for this report (Plate 2, in pocket, Table 1, p. 8).

Structure

Structurally, the Buckingham area consists of the northwestward-dipping section of early Paleozoic rocks which were upthrown along the Furlong fault at the southeast against Triassic Lockatong and Brunswick Lithofacies. An early report refers to a "Paleozoic island" (Lyman, 1895) amid a sea of New Red sedimentary formations. Not until near the close of the last century, largely through the work of I. C. Russell

FIGURE 3

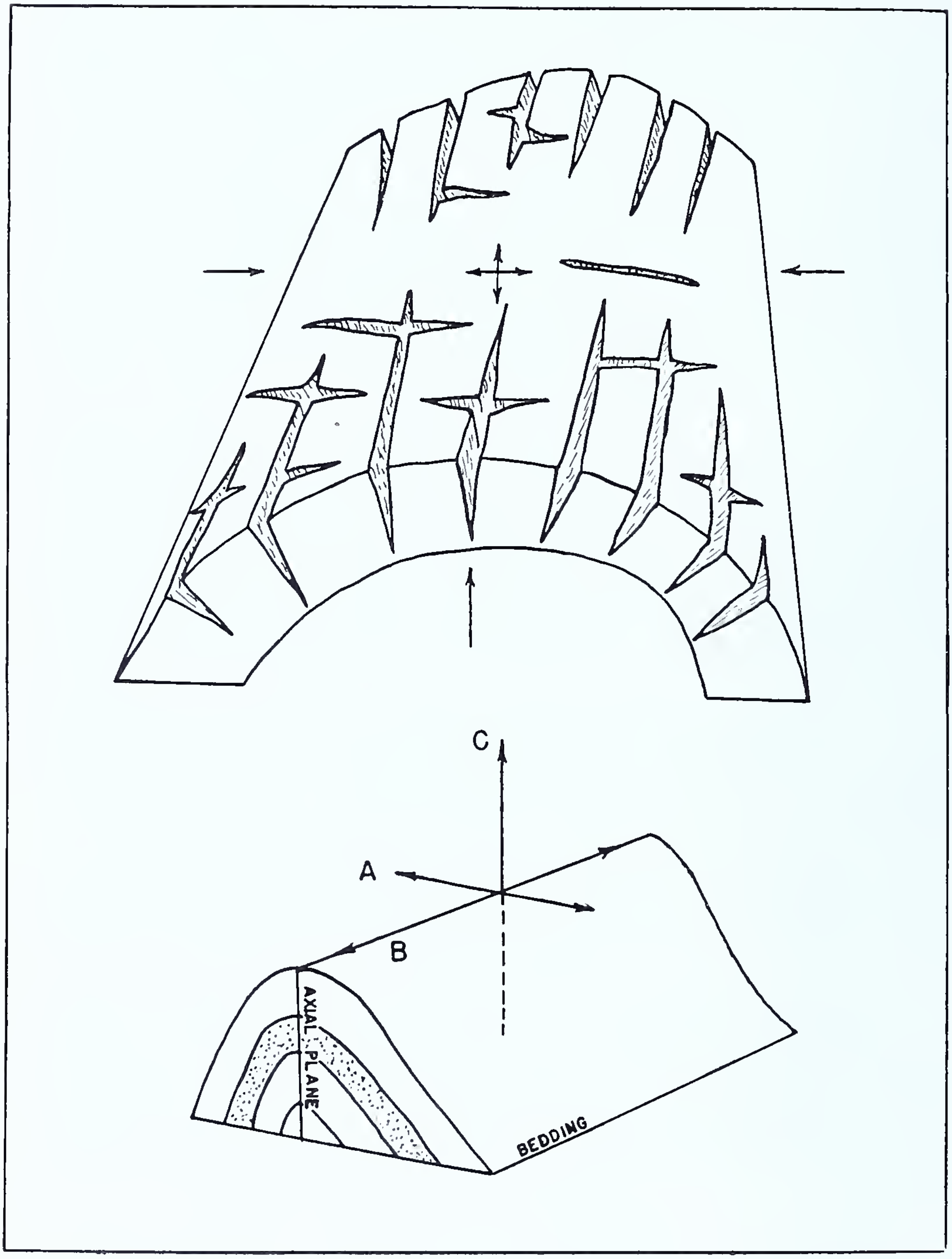


Diagram of a fold located in a coordinate system of three axes: a, b and c. Plane of ac is perpendicular to axial plane indicated by bc. From Lessentine, after Cloos.

(1889) and Henry B. Kümmel (1897), was its fault block nature established. Faulting has been a more dominant response to the stresses applied to the Buckingham area during the post-Triassic Palisade disturbance.

The southern border of the Paleozoic rocks is a steep to vertical fault with a stratigraphic displacement of at least 10,000 feet. On the southern, downstream side, the Brunswick and Lockatong Lithofacies are exposed. The oldest rock type adjacent to the fault observed on the northern upthrown side is the Pre-Cambrian quartz diorite in Buckingham Mountain (Chapter II, p. 16) (Bascom, 1931, p. 187 and Plate 1, in pocket). The Furlong fault extends southwestward beyond the limit of the Paleozoic formations, and merges with the Chalfont fault (Chapter IV). Northeastward, as the Flemington fault, it is a major structure in the Triassic rocks of New Jersey. The significance of the fault is not only the magnitude of its throw, but its interpretation as a fault block in which Triassic and Paleozoic rocks have been tilted to the north. Along the northern edge of the Paleozoic rocks, the basal Stockton Lithofacies of the Newark group rests unconformably on the Cambrian and Ordovician (?) limestones. Removal of the Triassic rocks by erosion has laid bare the floor upon which those sediments accumulated and gives a local picture of the basement as it may have appeared at the opening of Newark time. Comparable areas where the early Paleozoic formations emerge from under the cover of Triassic rocks show farther west in Lancaster and Chester Counties, Pennsylvania, and northeastward in Hunterdon County, New Jersey. The only other fault indicated on the geological map (Plate 2, in pocket) is where the patch of Cocalico (?) Phyllite west of Furlong is downthrown against Paleozoic limestones on the east by a steep to vertical fault.

There are indications of numerous faults which are too small or for which there are too little data to map. One of these showed in an excavation for a dam in the stream valley south of Solebury where Lower Cambrian quartzite was observed in fault contact with Upper Cambrian limestone.

It is difficult, without postulating a rather complex fault pattern, to account for the isolated Chickies Quartzite ridges. Lessentine (1952) concluded that the low area underlain by limestone between Buckingham and Little Buckingham Mountains is a graben. Sericitic shale in the soil may indicate Elbrook (?) (Leithsville) Limestone, Lessentine (1952) reported cryptozoa at the foot of the north side of Little Buckingham Mountain.

Jointing is well developed in the Paleozoic rocks of the Buckingham area. Recently, Lessentine (1952, p. 29-30) studied these joints in an attempt to determine their origin, relationship to the fold axes and the predominant northwest dip of the beds (Figure 3, p. 36). He wrote:

> There are three major joint sets and several minor sets developed in the area. Two of the sets can be referred to the coordinate axes a, b, and c which are closely related to the elements of the folds (Cloos, E., 1937).
>
> One major set of joints dips uniformly to the southeast about 70 degrees and is approximately parallel to the strike of the beds. With reference to the coordinate axes, this set has been designated the "bc" or longitudinal set. . . . As a rule the bc

> joints form smooth plane surfaces. A second major set, designated the "ac" set, is about normal to the axes of the folds. The joints in the second set are vertical or dip steeply to the northeast or southwest. The ac joints are abundant and have aided in quarrying the stone in the past.
>
> A third major set of joints is vertical or dips steeply and strikes roughly north-south. They cut across the strike of the beds at angles between 30 and 45 degrees, and are called diagonal joints.
>
> * * *
>
> The writer believes that the origin of the ac and bc joints may be best explained as the result of tension. . . . The bc joints are regarded as tension fractures developed parallel to the b axis of the coordinate system as a result of upward flexing. The ac joints are believed due to elongation in b, i.e. tension joints developed normal to stretching that paralleled the fold axes. . . . No explanation is given for the origin of the diagonal joints.
>
> The ac and bc joint sets form a uniform joint system which is thought to have developed in the Paleozoic rocks during folding at the end of the Paleozoic era. They are the result of regional stress which had a large horizontal component.

* * *

Stratigraphy

All of the Paleozoic formations in the Buckingham area are of Cambrian or Ordovician (?) ages. They are dominantly carbonate rocks which may be correlated with those in the Durham area and the Lehigh Valley. The Paleozoic formations in the Buckingham area include: Chickies Quartzite with its basal member, the Hellam Conglomerate, Elbrook (?) (Leithsville) Limestone, Conococheague (Limeport) Limestone of Cambrian age, and Beekmantown (?) Limestone and Cocalico (?) Shale of Ordovician (?) age. Basic dikes are injected into the Cambro-Ordovician rocks.

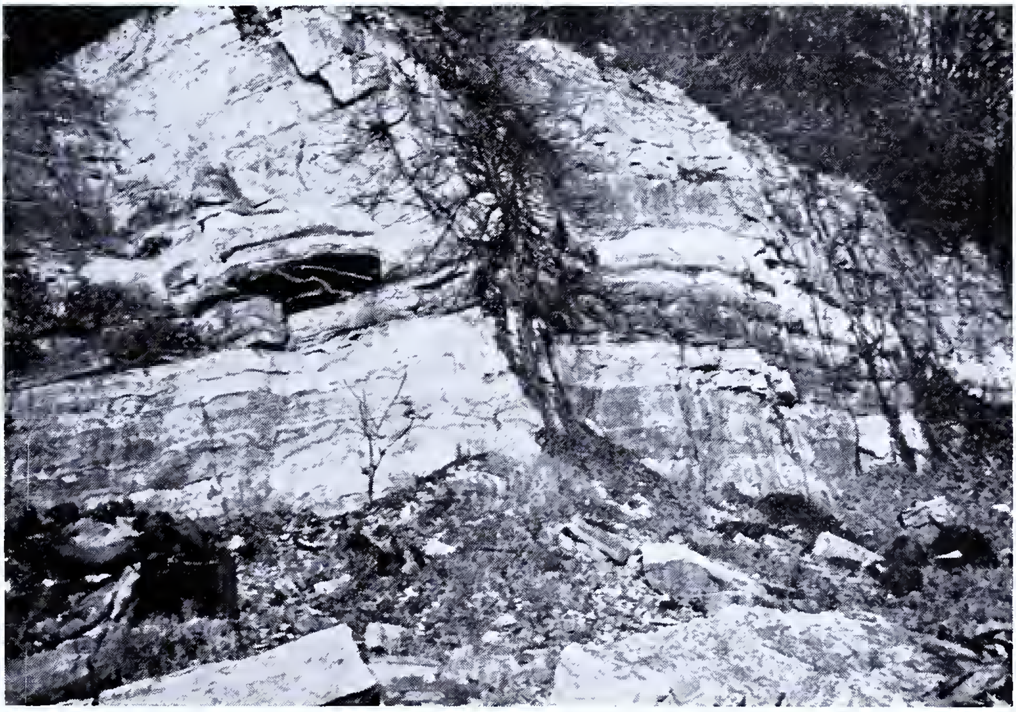
The stratigraphy of the Buckingham area differs from that in the Durham area in that it includes two formations, the Beekmantown (?) Limestone and Cocalico (?) Phyllite, assigned to the Ordovician. The limestones are included in the undifferentiated Cambrian and Lower Ordovician carbonates called Kittatiny Limestone by the New Jersey Geological Survey (Kümmel and Weller, 1901) and Shenandoah Limestone by Bascom and others (1909b). Plates 5, 6 and 7 illustrate some of the features of the limestones in the Buckingham area.

Chickies Quartzite

The Chickies Quartzite is the oldest Paleozoic formation in the Buckingham area. The name was first used in 1876 by J. P. Lesley, who spelled it "Chiques" from Chiques Rock on the Susquehanna River above Columbia, Pennsylvania. Lesley threw doubt upon supposed correlation with Potsdam Sandstone of New York. More recent writers, particularly Stose, and Jonas (1922), have described the Chickies Quartzite in modern terms. It is generally massive, light-gray to buff, vitreous to arkosic quartzite with some interlayered schist. In its lower part occurs the Hellam Conglomerate member. There is confusion as to the use of Hellam Conglomerate as a separate unit or a member of the Chickies Quartzite. The latter use is followed in the present discussion as serving to distinguish the Chickies Quartzite from the Hardyston Quartzite (p. 25). *Scolithus* is common as small, vertical tubes filled with sand. A thickness of 400 feet is an average for south-central Pennsylvania.

Plate 5

A. Old lime kilns at Limeport. Photo by B. L. Miller.



B. North wall of north quarry at Limeport showing north-dipping beds of Conococheague (Limeport) Limestone. Photo by B. L. Miller

Hardyston Quartzite was used in Bulletin 828 (Bascom and others, 1931) for the quartzite in Buckingham Mountains but Chickies is preferable, because of the presence there of the Hellam Conglomerate and its absence from the type Hardyston Quartzite of New Jersey, in the Lehigh Valley and the Durham area.

The Chickies Quartzite of Buckingham and Little Buckingham Mountains is dominantly fine-grained, white, thick-bedded, glassy quartzite, which is pebbly in its lower Hellam Conglomerate member. The best exposure is in a large, abandoned quarry on the southwest flank of Buckingham Mountain. In this quarry the lower part of the rear wall is white, vitreous quartzite, the upper part conglomeratic with stretched white quartz (navy bean) pebbles. At the base, red feldspar and quartz pebbles up to an inch in diameter stand out from bluish-purple cement of a crumbly arkose. The lowest 25 feet is said to rest upon a red and green banded, sandy clay "regolith" with residual feldspar fragments (Bascom and others, 1931, p. 18, and Chapter II, p. 16). Some purplish beds are found among the white quartzite. About a hundred feet above the quarry lip more massive, vitreous quartzite is encountered (Plate 3, B). On the north side of Buckingham Mountain, three-tenths mile northeast of Buckingham Valley village, some of the quartzite which must be near the top of the formation is composed of spherical quartz grains. Bulletin 828 contains the following section (Bascom and others, 1931, p. 18):

	Feet
Massive, vitreous quartzite and conglomerate	165
Thin-bedded quartzite	100
Pebbly quartzite and conglomerate	25
Total	290

This section does not represent the total thickness of the Chickies Quartzite in Buckingham Mountain. Calculating from scanty data, a thickness of the order of 900 feet is indicated. There are doubtless local faults, one of which was observed in the quarry in Buckingham Mountain. The lower 300 feet may be assigned to the Hellam Conglomerate because of its pebbly texture. No indication of the overlying Antietam sandstone was found in Buckingham Mountain.

The surface distribution of the Chickies Quartzite is limited to Buckingham and Little Buckingham Mountains. In a new dam site in the stream valley two-tenths of a mile south of Solebury, quartzite was observed in contact with broken and distorted Conococheague (Limeport) Limestone. The quartzite is impure, sandy, fractured and includes some gray shale, and was presumably brought up along an otherwise unknown fault.

The early Cambrian age of the Chickies Quartzite is based upon correlation with other areas where it is fossiliferous and upon the finding of a fragment of *Olenellus* in Buckingham Mountain by Wherry (Bascom and others, 1931).

The upper contact of the Chickies Quartzite is not exposed. The lower contact, now hidden, is said to be with Pre-Cambrian crystalline rocks (Chapter II, p. 16). Along the fault contact with Triassic rock south of Mt. Gilead Church, fault breccia is exposed in a small, abandoned quarry or ochre pit. The dense, massive quartzite has been highly sheared. Its purple color and the presence of a small amount of brownish conglomerate suggest a stratigraphic position low in the formation.

Elbrook (?) (Leithsville) Limestone

One might expect beds overlying Chickies Quartzite to belong to Antietam Sandstone followed by Tomstown Dolomite. Neither Antietam Sandstone nor Tomstown Dolomite has been proved to underlie any portion of the Buckingham area.

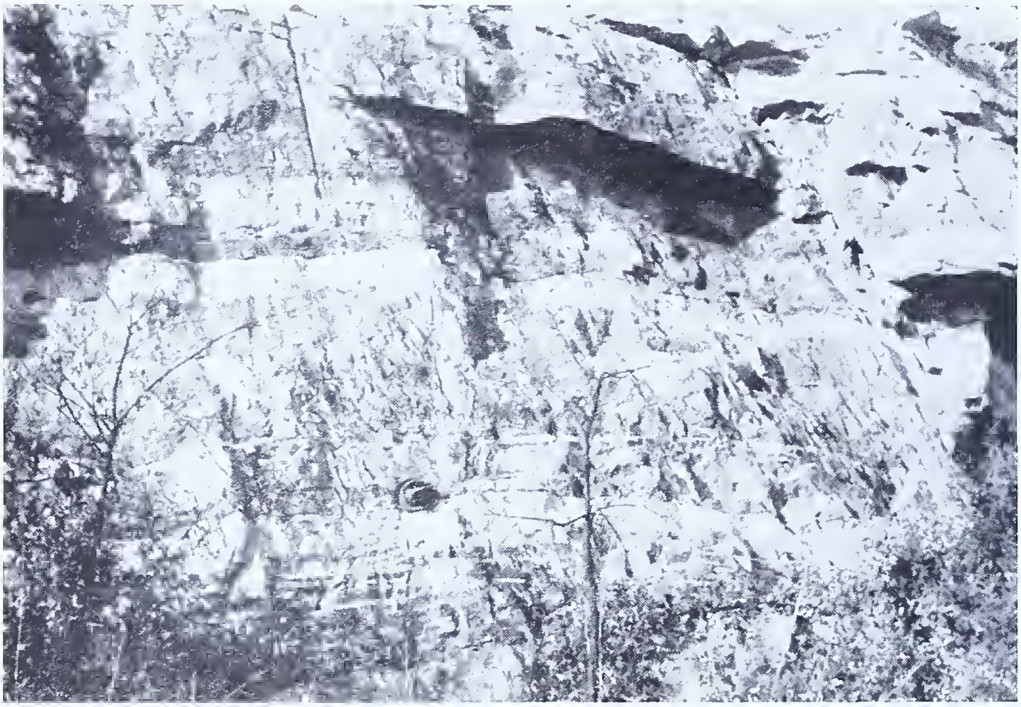
Elbrook was the name proposed by Stose (1906) for a limestone in Franklin County, Pennsylvania. In its type locality the rock is massive, blue-gray, magnesium limestone and chert, interbedded with red and green shales. Its thickness of 2,000 feet separates the overlying Conococheague Limestone from the underlying Waynesboro Limestone. Its correlation with the Elbrook (?) (Leithsville) Limestone of Buckingham Valley is doubtful and the latter is written with a query. Howell, Roberts and Willard (1950) correlated Elbrook (?) Limestone with Leithsville Limestone. For reasons already expressed (p. 10), the names are combined in this report.

The Elbrook (?) (Leithsville) Limestone was mapped (Bascom and others, 1931) as a broad band from Furlong to a point about a mile northeast of Lahaska Station. Another small slice was caught along the great fault six-tenths of a mile east of Aquetong.

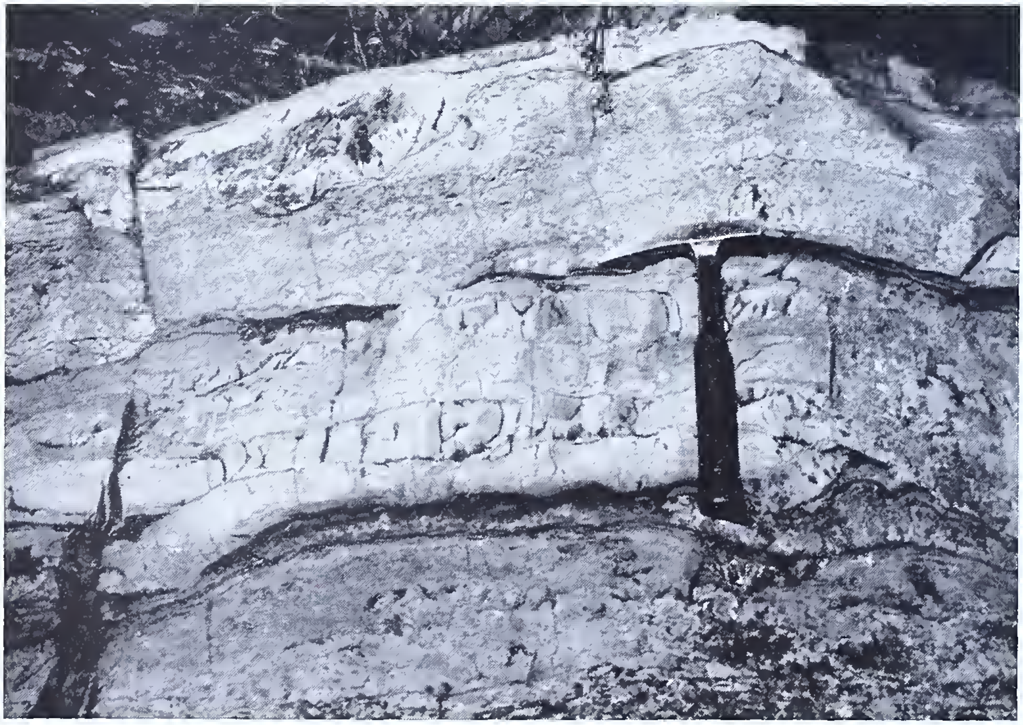
The Elbrook (?) (Leithsville) Limestone is exposed in a number of quarries, particularly a large one a mile east of Buckingham. It is light-blue to gray limestone, including some calcareous shale, which appears to increase proportionally downward (Bascom and others, 1931, p. 20-21). Some of the thicker strata are laminated, and reddish and gray shales have been reported. Toward the middle of the formation dolomite associated with sandy or quartzitic beds weathers buff and yields sandy fragments or plates. Bascom and others (1931, p. 21) mention a cemented quartz breccia along the southeastern part of the area mapped as "Elbrook" limestone. This occurrence suggests a fault separating Elbrook (?) (Leithsville) Limestone from Chickies Quartzite to the south. Ripple marks, mud cracks and local black chert layers have been observed in the formation. The residual soil from Elbrook (?) (Leithsville) Limestone contains sericitic shale chips which are useful in mapping.

The thickness of the Elbrook (?) (Leithsville) Limestone is between 400 and 600 feet. Neither upper nor lower contact of the Elbrook (?) (Leithsville) limestone has been observed. The lower contact is concealed and the upper contact cannot be drawn sharply. When lithologic change is noted from laminated or shaly beds, upward to alternating dark- and light-banded Conococheague (Limeport) Limestone with oölites and "*Cryptozoa*," it is assumed that the contact has been passed. It is probably transitional.

PLATE 6



A. Exposure of Conococheague (Limeport) Limestone, abandoned quarry south of highway ¾ mile east of Lahaska. Photo by B. L. Miller.



B. Detail of Conococheague (Limeport) Limestone in abandoned quarry south of highway ¾ mile east of Lahaska. Note conglomeratic bed above hammer, stromatolites below. Photo by B. L. Miller.

Age and correlation

The Elbrook (?) (Leithsville) Limestone is correlated with the type area on lithology and stratigraphic position. No fossils have been found in it in Bucks County. Its age can be limited between the early Cambrian Chickies Quartzite and the late Cambrian Conococheague (Limeport) Limestone.

Conococheague (Limeport) Limestone

The name Conococheague Limestone was used in Bulletin 828 (Bascom and others, 1931, p. 21). Although Limeport Limestone was proposed by Howell, Roberts and Willard (1950) for the type locality at Limeport at the extreme eastern end of Buckingham Valley, Conococheague (Limeport) Limestone is used in this report (p. 1 and Table 4, p. 28). The Conococheague (Limeport) Limestone in the Buckingham area is similar to that in the Durham area (p. 31). Years ago, when much lime was burned in Buckingham Valley, the Conococheague (Limeport) Limestone was a favorite source of stone. Therefore, the surface it underlies is pockmarked by quarries, only one of which is now in operation. Though there are many openings, no complete section has been observed.

The distribution of Conococheague (Limeport) Limestone is indicated (Plate 2, in pocket) as a band adjacent to and along the northwest side of Elbrook (?) (Leithsville) Limestone, extending from the valley of Watsons Creek northeast of Furlong, northeastward as a strip about one mile wide to Solebury School. From there it shrinks to a quarter of a mile in width on the Delaware River at Limeport and is not recorded in New Jersey. Present mapping is nearly identical with that in Bulletin 828 (Bascom and others, 1931).

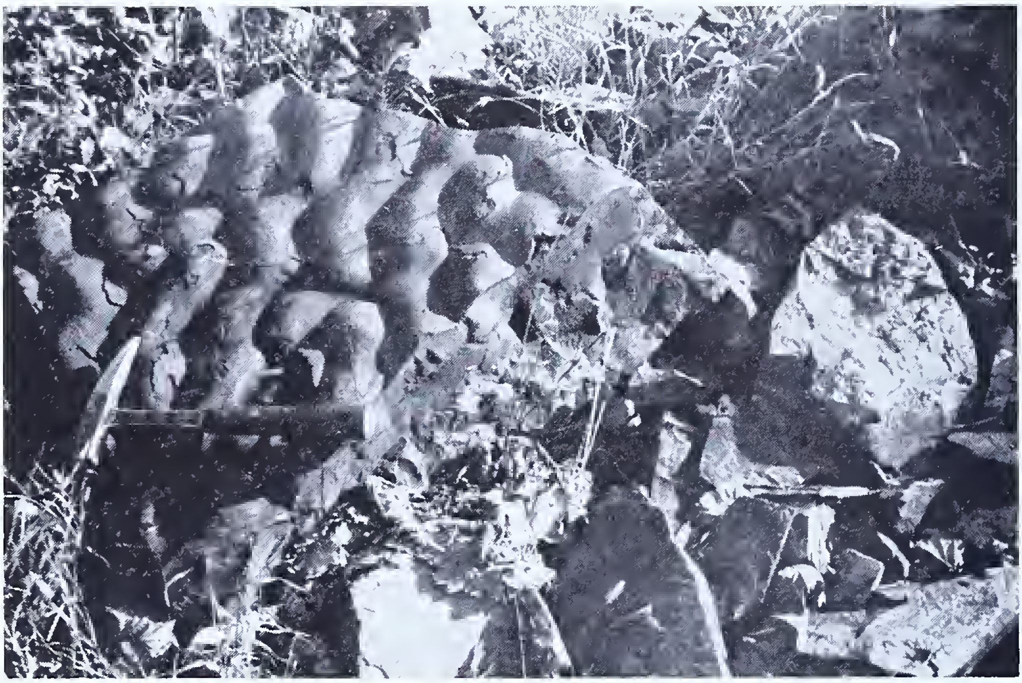
The Conococheague (Limeport) Limestone consists of massive, dense, dark- to light-blue carbonate rock, usually close to true dolomite in composition. Thin, wavy, argillaceous and black chert partings are less numerous than quartz sandstone beds. Some of the rock is dark-gray and siliceous, and whereas oölites and edgewise conglomerate are common, ripple marks were observed in only a few places. Bulletin 828 records the observation of phosphatic nodules. The rock weathers to deep clay soil in which there may be slabby, partly weathered limestone fragments. In quarry faces or other large exposures the rock may show rhythmic repetition of dark and light bands. The following analyses in Table 7, p. 43 (Miller, 1934) indicate the composition of the Conococheague (Limeport) Limestone in Buckingham Valley:

TABLE 7. *Chemical Analyses of the Conococheague (Limeport) Limestone in Buckingham Valley*

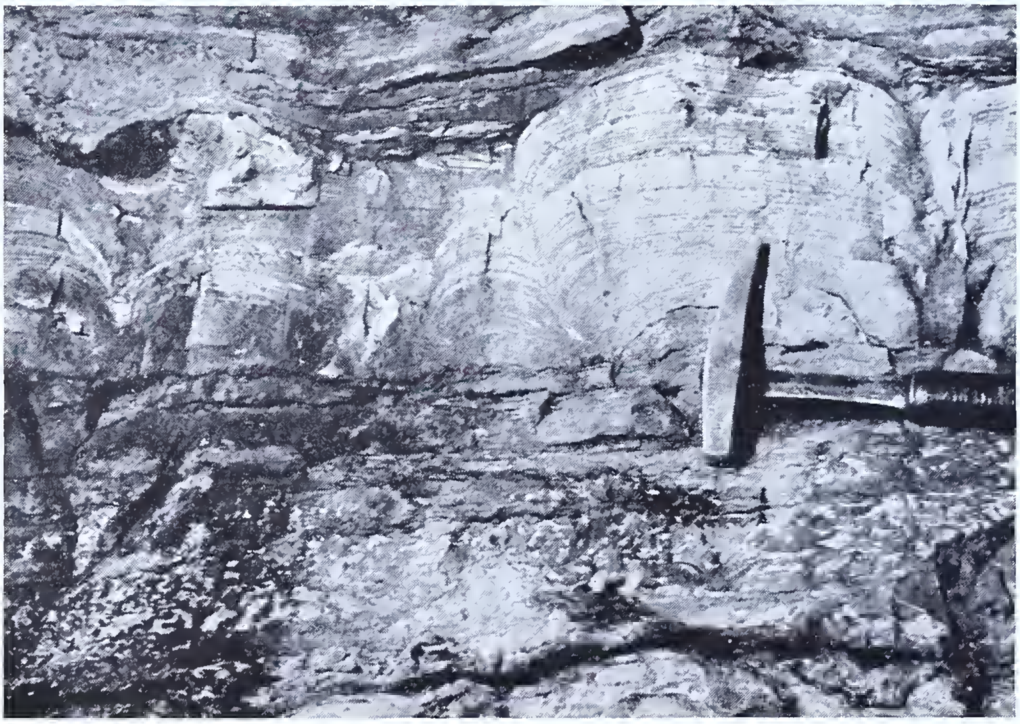
	1	*2*	*3*	*4*
$CaCO_3$	52.50	56.25	53.49	57.60
$MgCO_3$	42.11	31.91	40.32	18.16
SiO_2	3.60	6.84	5.53	16.80
Al_2O_3	.65	2.64	....	5.01
Fe_2O_3	1.10	1.20	....	1.71

Numbers 1 and 2 are of samples from the William Ely property 2½ miles northwest of New Hope. Number 3 is from the quarry of Herbert Havens at Limeport and number 4 is from a quarry 2 miles northwest of New Hope.

PLATE 7



A. Ripple marks in Conococheague (Limeport) Limestone in abandoned quarry south of highway ¾ mile east of Lahaska. Photo by B. L. Miller.



B. *Cryptozoön fieldi* in abandoned quarry in Conococheague (Limeport) Limestone south of highway ¾ mile east of Lahaska. Photo by B. L. Miller.

In the first large abandoned quarry west of the Delaware River at Limeport is a restricted occurrence of a red shale band near the top of the Conococheague (Limeport) Limestone. When first seen it was assigned to the Triassic, but its dissimilarity from Stockton Lithofacies is apparent on closer examination. The red shale, usually slaty, is interbedded with limestone. The bedding surfaces commonly show concentric color lines which penetrate the laminae. The red shale has been identified by fragments in the soil westward from Limeport to the vicinity of Solebury School. The overlying Triassic rocks are coarse-grained arkose and conglomerate of Stockton Lithofacies.

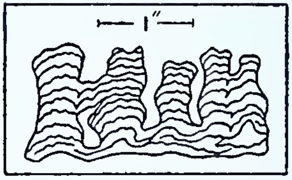
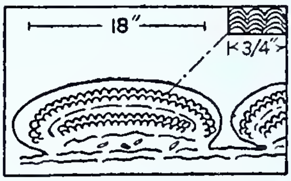
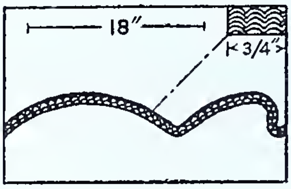
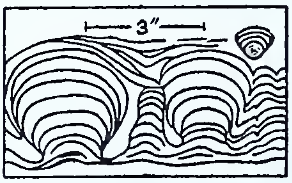
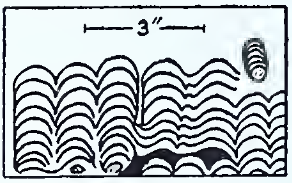
Brecciated limestone and the red shale are exposed in two small abandoned quarries north of the state road running east from Solebury School. More red shale and limestone were found at a small, abandoned pit in the eastern part of the school grounds. This is the farthest west they were identified. The significance of the red shale is that it comes at or very near the top of the Conococheague (Limeport) Limestone, serves as an approximate boundary with the overlying Beekmantown (?) Limestone, and may indicate disconformable relations between the two inasmuch as the upper Conococheague (Allentown Limestone) dolomite is absent.

The age of the Conococheague (Limeport) Limestone is established through the identification of late Cambrian fossils from the Limeport quarries by B. F. Howell (1957). These are Dresbachian or early, late Cambrian and similar to a faunule from Carpentersville, New Jersey (Weller, 1903). Calcareous algae (p. 46) have been identified by Henry Roberts (Howell, Roberts and Willard, 1950). These remains afford a means of correlation with Durham and Lehigh Valleys. The following comments on the fauna are quoted from Howell's report (1957, p. 25).

> The brachiopods, trilobites, and conchostracans . . . indicate that several different Dresbachian (early Late Cambrian) faunas or faunules are represented by the fossils in the beds of the Limeport formation in Bucks County. All of them are probably faunas or faunules of the early Dresbachian . . .
>
> Four faunas or faunules appear to be represented. These are the *Welleraspis lata* fauna or faunule, which is found in the beds *below* the disconformity in the southern quarry at Limeport; the *Talbotina pennsylvanica* fauna or faunule, in the beds *above* the disconformity in that quarry; the fauna or faunule whose commonest species is *Bucksella brevis* that is present in beds about 2 miles northwest of New Hope; and the fauna or faunule whose commonest species is *Lingulepis pinnaformis.* These faunas or faunules will be referred to in the following discussion as the *Welleraspis lata* fauna, the *Talbotina pennsylvanica* fauna, the *Bucksella brevis* fauna, and the *Lingulepis pinnaformis* fauna.
>
> The *Welleraspis lata* fauna contains, in addition to *Welleraspis lata,* the trilobites *Pemphigaspis franklini, Talbotina clara, Bucksella solitaria, Lonchocephalus angustus, Coosella lata,* and *Genevievella pennsylvanica,* the conchostracans *Indianites minutus, I. limeportensis,* and *I. perpusillus,* and the brachiopod, *Lingulella modesta.*
>
> The *Talbotina pennsylvanica* fauna contains, in addition to *Talbotina pennsylvanica,* the trilobites *Bucksella limeportensis* and *Lonchocephalus pennsylvanicus* and the brachiopod *Lingulepis limeportensis.*
>
> The *Bucksella brevis* fauna contains, in addition to *Bucksella brevis,* the trilobites *Bucksella longa, B. limeportensis, Welleraspis humilis, Talbotina botina* aff. *degrasensis, Lonchocephalus parvulus, Coosia parva,* and the brachiopod, *Lingulella rugosa.*
>
> The *Lingulepis pinnaformis* fauna contains *Lingulepis pinnaformis, Lingulepis limeportensis, Lingulella* aff. *prima* and the unidentified trilobite whose pleuron is described on an earlier page.

In addition to these four faunas there are present in the Limeport formation at least two floras of calcareous algae—the flora whose three known species are *Cryptozoön fieldi* Fenton and Fenton, *Dolatophycus expansus* Fenton and Fenton and *Archaeozoön undulatum* (Bassler) that is found in the northern quarry at Limeport, apparently stratigraphically above the *Talbotina pennsylvanica* fauna, and a flora that contains an undescribed large, dome-shaped calcareous alga.

PLATE 8

Formation	Lithology				Stromatolites			
Allentown Limestone	Oölites and conglomerates abundant	Shale rare	Sandy	Upper beds rather uniform in thickness; lower beds variable. Weathered outcrops show alternating light and dark beds, distinctly in upper part, less so in lower. Conglomerates and disconformities less abundant than in the Limeport.	Biostromes	Stromatolites	*Anomalophycus compactus*	
							Form-species A (new)	
							Form-species B (new)	
Limeport Limestone		Interbedded shales common	Very sandy	Very variable in thickness and argillaceous content. Argillaceous beds weather dirty white to cream, other beds dark gray with whitish bands or streaks. Conglomerates very abundant; many local disconformities. Shale less abundant than in the Leithsville.			*Cryptozoon fieldii*	
							Archaeozoon undulatum	
Leithsville Limestone	Oölites and conglomerates absent or scanty		Not sandy	Thick-bedded, often with masses of dark or light chert. Bedding variable toward top with thin interbedded shales. Upper beds often show whitish bands when weathered.	No biostromes	Doubtful stromatolites in upper part	?	

Key to the identification of the Cambrian limestone formations and their stromatolites (after Roberts in Howell, *et al.* 1950).

The lower contact of the Conococheague (Limeport) Limestone, as indicated (p. 41) is gradational. The upper contact with the Beekmantown (?) Limestone may be approximately indicated by the red shale, but where this is absent, the separation can be marked only negatively through the disappearance of the *"Cryptozoa,"* the oölites and the alternating dark and light bands typical of Conococheague (Limeport) Limestone. No Conococheague (Allentown) Limestone as discussed for the Durham area has been recognized in Buckingham Valley.

Calculated from discontinuous exposures, the thickness of the Conococheague (Limeport) Limestone in Buckingham Valley is about 400 to 500 feet.

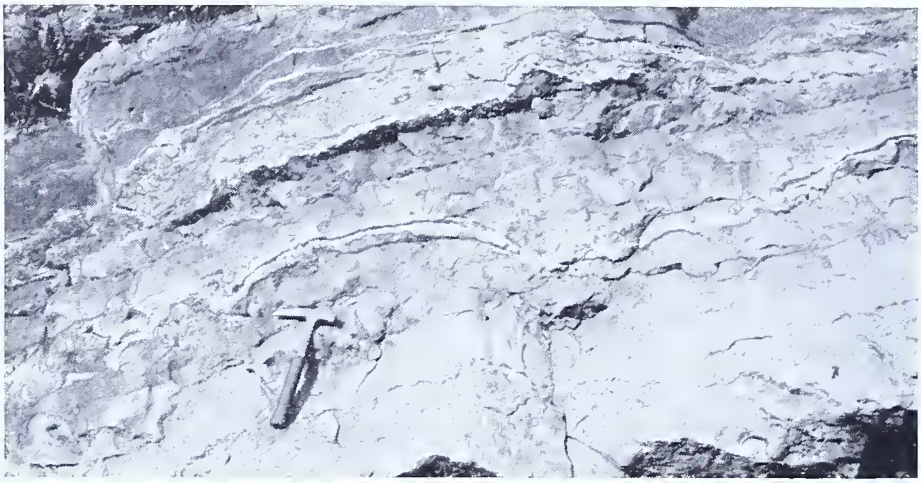
Beekmantown (?) Limestone

The Beekmantown (?) Limestone overlies Conococheague (Limeport) Limestone in the Buckingham area. Originally named by John M. Clarke in 1899 for the village of Beekmantown, New York, the name has a wide application in the northern Appalachian region. There have been deviations from the original use. It was included in the upper part of the Kittatinny (Kümmel and Weller, 1901) and Shenandoah (Bascom and others, 1909b) formations. Although Beekmantown Limestone has been subdivided in central Pennsylvania, it has not been subdivided in eastern Pennsylvania where the name is applied to a thick succession of limestone and dolomite of early Ordovician age. J. P. Hobson has recently (1957) broken the Beekmantown at Reading, Pennsylvania into four formations. His subdivisions have not yet been applied farther east. In the Lehigh Valley Beekmantown Limestone, which is similar to that in the Buckingham area, overlies the late Cambrian (Trempealeauian) Allentown Limestone and is overlain by the Jacksonburg Limestone of Trenton age. Lithologically, the Beekmantown (?) Limestone is quite unlike Conococheague (Limeport) Limestone and only through a facies shift could it be a modified Conococheague (Allentown) Limestone. By a process of elimination, there is no other Paleozoic limestone than the Beekmantown Limestone in eastern Pennsylvania to which these beds can be assigned.

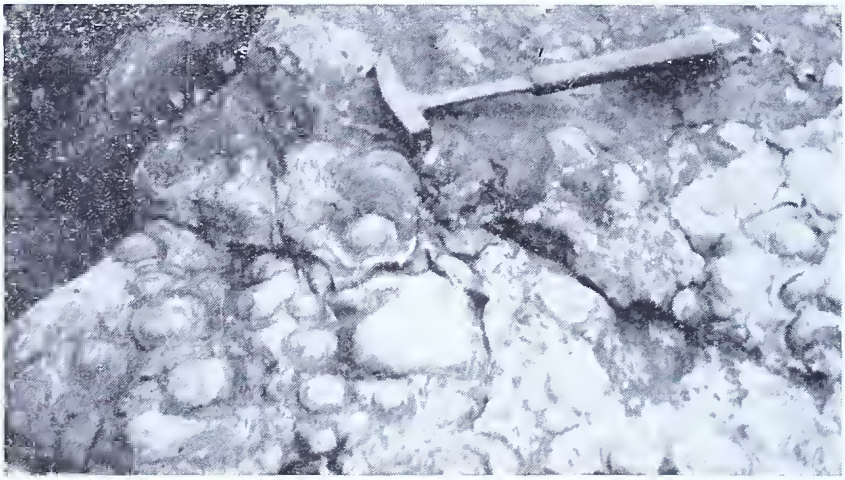
In the Buckingham area the Beekmantown (?) Limestone occupies two elongate patches adjacent to the Conococheague (Limeport) Limestone along the northwestern fringe of Buckingham Valley. Quarries northwest and north of Aquetong afford some of the best exposures. Lessentine (1952) believed that another narrow band of supposed Beekmantown (?) Limestone lies north of Watson Creek.

The Beekmantown (?) Limestone is massive, fine-grained, dolomitic limestone, ranging from light- to dark-blue or blue-gray. Locally, the rock may be siliceous or flinty, laminated or shaly, or an edgewise conglomerate. Lessentine (1952) commented that there is at the base of the Beekmantown (?) Limestone "a persistent band of oölitic chert which has been traced from Lahaska to Buckingham where it disappears." It is believed to reappear again southwest of Hughesian School. The more massive beds range to ten feet thick. "Bassler's (1919) description of the Stonehenge member of the Beekmantown (?) Limestone in southern Pennsylvania and Maryland is similar to the Beekmantown (?) Limestone of this area."

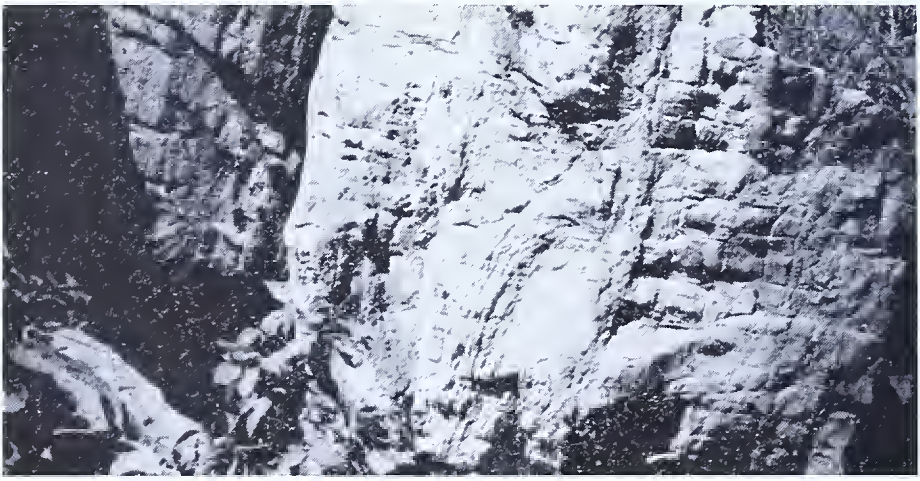
PLATE 9



A. Undescribed stromatolite, Allentown Limestone, Nancy Run section, Northampton County, Pennsylvania. Photo by H. G. Richards.



B. *Cryptozoön fieldi* (Fenton and Fenton), Limeport Limestone, Carpentersville, New Jersey. Photo by H. G. Richards.



C. Undescribed stromatolites, Allentown Limestone, Nancy Run section, Northampton County, Pennsylvania. Photo by H. G. Richards.

Because of the presence of the red shale band noted at or near the top of the Conococheague (Limeport) Limestone, the Cambrian-Ordovician contact is inferred to be disconformable. According to Lessentine (1952), as this band is lost southwest of Solebury School, the boundary between Beekmantown (?) Limestone and Conococheague (Limeport) Limestone beyond that point is uncertain. The upper contact with Cocalico (?) Phyllite is unknown. The Beekmantown (?) Limestone is unconformably overlain by Triassic Stockton Lithofacies.

Inasmuch as no fossils have been found in Beekmantown (?) Limestone in the Buckingham area, its age cannot be based on paleontological data. If it is the correlative of Beekmantown Limestone in the Lehigh Valley where *Lecanospira* has been found, its age is established.

Inasmuch as Beekmantown (?) Limestone is exposed only as a fringe next to the underlying Conococheague (Limeport) Limestone and its top is hidden beneath the overlying Stockton Lithofacies, the thickness cannot be given with accuracy. It is assumed that there are at least 1000 feet present.

Cocalico (?) Phyllite

Cocalico (?) Phyllite is the youngest Paleozoic formation in the Buckingham area, and in Bucks County. The type rock was christened by Stose and Jonas (1922) from a locality in Lancaster County, Pennsylvania. They described it as dark-gray shale and thin, crinoidal limestone which became variegated slate upward. Normanskill-type graptolites were found in it. The name is also applied to patches of phyllite once called Martinsburg shale in Pennsylvania. It has a thickness at the type locality of about 1000 feet. Recent usage by the U. S. Geological Survey restricts Martinsburg Shale to areas north of the Triassic belt and Cocalico Phyllite to those south of it. A partial equivalence is indicated. The Bucks County Cocalico (?) Phyllite is in the middle of the Triassic belt, but lithologically more closely resembles Cocalico Phyllite than Martinsburg Shale.

A small, triangular patch of phyllite west of Furlong has been assigned to the Cocalico (?) because of its similarity to the Cocalico Phyllite farther west. It is in fault contact on the east with Cambrian limestones and on the south with the Triassic Lockatong Lithofacies. On the north it is unconformably overlain by the Triassic Stockton Lithofacies. This contact is readily detected in the field as the phyllite is supplanted by the coarse-grained arkose and conglomerate of the Stockton Lithofacies. The Cocalico (?) Phyllite is not well exposed, but may be seen along the highway north of Furlong. Lithologically, it is a fissile to slaty, black, blue, purplish or gray phyllite. The hard, platy layers are stained by concentric color lines. Fracture surfaces parallel to the phyllitic layering are smooth and shiny. The obscure bedding probably dips gently north under the Triassic rocks. Half a mile west of Furlong where the Cocalico (?) Phyllite underlies a small hill, the rocks become sandy. Little is to be seen in place, but fragments of sandstone are plentiful in the soil.

No definite thickness can be assigned to the Cocalico (?) Phyllite, as nothing is known of its lower contact. The upper contact is hidden under the Stockton Lithofacies. Judging from the relief of the hill west of Furlong and the supposed north dip of the Cocalico (?) Phyllite, a thickness of approximately 200 feet is exposed. The occurrence of the sandstone beds above the phyllitic layers is similar to localities in the Martinsburg Shale, but any correlation is speculative.

LANGHORNE AREA

The third Paleozoic area is in the southern part of Bucks County and, inasmuch as it touches the south side of Langhorne, is designated the Langhorne area (Fig. 1, p. 24). The Lower Cambrian Chickies Quartzite is the only Paleozoic formation in the Langhorne area. It enters Bucks County on the east at the Delaware River opposite Trenton and trends about S. 60° W. as a narrow band to the Bucks-Montgomery County line, a mile and a half south of Feasterville. The lithology has been described in the Philadelphia and Trenton folios (Bascom and others, 1909a and 1909b). The main body of Chickies Quartzite is gray crystalline quartzite and light buff to white, feldspathic, sericitic quartz schist. At its base the Hellam Conglomerate member contains elongated blue quartz pebbles questionably said to come from Baltimore Gneiss to the north. Cleavage is parallel to bedding. A thickness of 1300 feet was assigned to these steeply south-dipping strata (Bascom, 1909a and 1909b).

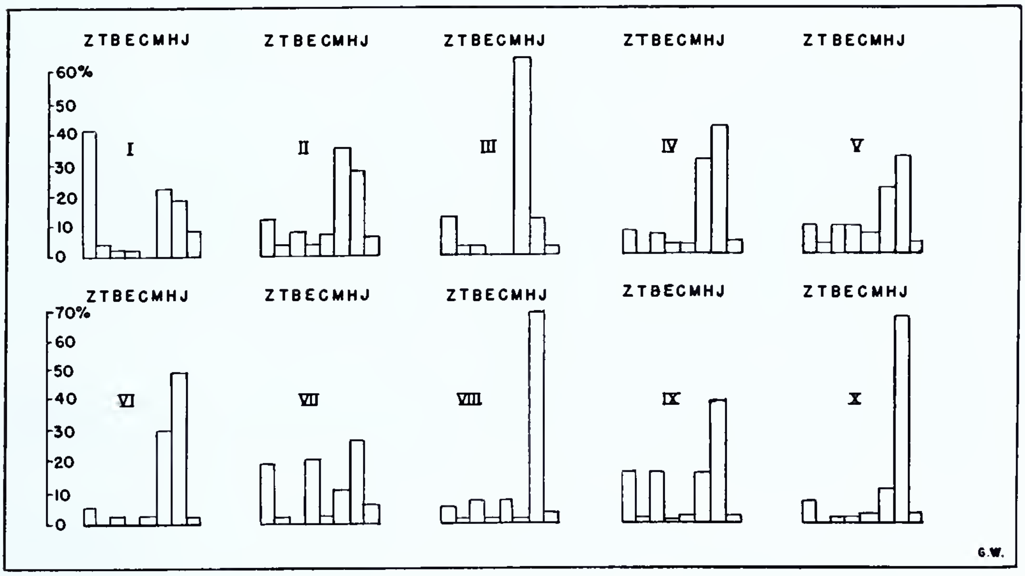
The age and correlation of Chickies Quartzite in the Langhorne area depend on lithology and cannot be proved paleontologically. *Scolithus,* is the only organic remains reported. To the west, the age of the Chickies Quartzite has been determined as early Cambrian. Lithologically, it is little different from Chickies Quartzite with basal Hellam Conglomerate from the type locality at Chickies Rock above the Susquehanna River.

Although the formation supports a low, fairly continuous ridge, exposures are poor. At the northern, lower contact, Chickies Quartzite rests unconformably on the Pre-Cambrian Baltimore Gneiss. In a quarry north of Janney, faulting has occurred along this Cambrian-Pre-Cambrian contact (p. 21). Inasmuch as Baltimore Gneiss is believed to be the correlative of the Byram and Pochuck Gneisses in the north with which it is lithologically similar (Dr. Watson, personal communication), the quartzite-gneiss relations of the two areas should be similar (Chapter II). The upper contact along the southern border of the Chickies Quartzite is interpreted as a thrust fault, regardless of whether the metamorphic rocks to the south are Pre-Cambrian or Lower Paleozoic. The total absence of Cambrian limestone which normally overlies the Chickies Quartzite elsewhere is significant. It is unlikely that the limestone is absent through lack of deposition when it is known to have a thickness of several hundred feet in the Buckingham area and to reappear above the Chickies Quartzite west of the Langhorne area.

THE THREE PALEOZOIC AREAS CONTRASTED AND COMPARED

In comparing and contrasting the three Paleozoic areas of Bucks County the common denominator is the Lower Cambrian, Hardyston or Chickies Quartzite. Each of the three areas, Durham, Buckingham and Langhorne, contains quartzite of similar lithology. In the Buckingham and Langhorne areas, conglomerate in the lower part is referred to the Hellam member. Conglomerate is not present in the basal part of Hardyston Quartzite in the Durham area but conglomeratic zones occur higher in the section. Shale, slate, schist or phyllite, locally appear toward the top of the formation.

FIGURE 4



Histograms of samples of Cambrian quartzites based on studies of R. G. Petersen, Nos. I, II, III, Chickies Quartzite from Buckingham Mountain, all others, Hardyston Quartzite from Northampton County. See Table 8.

Hardyston Quartzite in Northampton County and in the Durham area rests unconformably on the Pre-Cambrian Byram and Pochuck Gneisses, a relation analogous to that in the Langhorne area between the Chickies Quartzite and the Pre-Cambrian crystalline rocks. Older accounts and personal communications indicate that Chickies Quartzite in Buckingham Mountain also rests unconformably on Pre-Cambrian quartz diorite (Chapter II, p. 16).

The relationships of the upper contact of the quartzite differ in the three areas. In Northampton County it may be transitional into the Tomstown Dolomite (Leithsville Limestone), although one disconformity has been recognized. The upper contact is transitional in the Durham area. Along the north flanks of the Buckingham Mountains, the contact is concealed under talus. In the Langhorne area the upper contact of the Chickies Quartzite is mapped as a fault separating it from overthrust metamorphic rocks of undetermined age.

Petersen (1948) made a comparative, petrographic analysis of Hardyston Quartzite from Northampton County and Chickies Quartzite from Buckingham Mountain. Figure 4 (p. 51) is a series of histograms based on Petersen's analyses. Numbers I, II and III are from Buckingham Mountain; the others, from various localities south of the Lehigh River, east of Bethlehem in Northampton County. Tabulated average percentages of Petersen's samples from Northampton County and Buckingham Mountain are given in Table 8.

TABLE 8. *Average percentage of minerals in Hardyston Quartzite, Northampton County, and Chickies Quartzite from Buckingham Mountain*

	Zircon	*Tourmaline*	*Biotite*	*Epidote*	*Chlorite*	*Magnetite*	*Hematite*	*Jasper*
Buckingham Mtn.	22.7	2.9	3.7	1.9	2.2	42.1	19.3	5.4
South Mountain	9.9	1.8	9.1	3.2	4.8	18.9	49.9	3.1

These data indicate that there is neither striking similarity nor marked divergence between the quartzites from the two areas except for the large difference in percentages of zircon and the reversal of proportions of magnetite to hematite. Probably the iron oxides are epigenetic. It seems safe to conclude from Petersen's study that Hardyston Quartzite of Northampton County and Chickies quartzite in the Buckingham Mountains had a similar provenance.

The thicknesses of the Cambrian quartzites recorded in Northampton County and the three areas in Bucks County, Table 9 and Figure 5, range progressively:

TABLE 9. *Maximum thicknesses of Hardyston Quartzite and Chickies Quartzite in Northampton and Bucks Counties*

	Feet
Northampton County	350
Durham area	300
Buckingham area	900
Langhorne area	1300

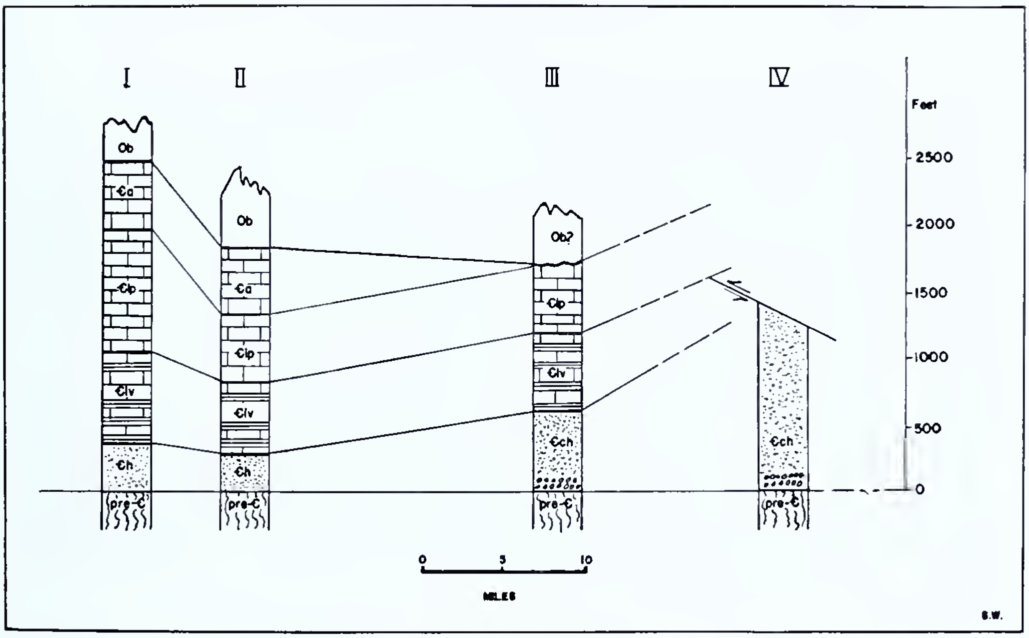
These maximum figures indicate a progressive thickening southward (Fig. 5 and Table 9). Simultaneous with the thickening, the Hellam Conglomerate comes in as the basal member. If the quartzite represents the initial incursion of the Cambrian sea into the Appalachian geosyncline with encroachment onto the fringe of Appalachia, thickness changes and lithologic variations run true to form. The formation thinned away from the shore and the basal conglomerate became more prominent nearer the coast line.

The Cambrian limestones in Bucks County are confined to the Durham and Buckingham areas. The lowest, Tomstown Dolomite (Leithsville Limestone) occurs in Northampton County and the Durham area. The Elbrook (?) (Leithsville) Limestone is in the Buckingham area. Respective maximum thicknesses are given in Table 10 (p. 52).

TABLE 10. *Average thicknesses of Tomstown Dolomite (Leithsville Limestone) and Elbrook (?) (Leithsville) Limestone in Northampton and Bucks Counties*

	Feet
Northampton County	900
Durham (Cook) Creek	800
Buckingham area	600
Langhorne area	absent

FIGURE 5



Columnar sections to indicate thickness changes and correlation among the Cambrian formations from the Lehigh Valley, Durham, Buckingham, and Langhorne areas.

These data indicate progressive thinning southward, the opposite of the quartzite. The shaliness of the Tomstown dolomite (Leithsville Limestone) is indicative of near-shore deposition. The thickness changes and lithology suggest thickening away from the shore into the geosyncline. When contrasted with the quartzites, the variation suggests *pari passu* thickness shifts. If the two formations represent even partly contemporaneous facies, an interesting relation is inferable. The conditions are diagrammed in Figure 5 (p. 53). Table 11 lists the thickness of the Conococheague (Allentown and Limeport) Limestone for the several areas:

TABLE 11. *Average thicknesses of Conococheague (Allentown-Limeport) Limestone in Northampton and Bucks Counties*

	Conococheague (Allentown) Ls.	*Conococheague (Limeport) Ls.*
Northampton County	500 feet	900 feet
Durham Creek	400	500
Buckingham Valley area	absent	400-500
Langhorne area	absent	absent

Again, there is an implied thinning southward, even though sequences are incomplete. Too little is known of the Beekmantown (?) Limestone to warrant comment. The single occurrence of Cocalico (?) Phyllite may indicate the incursion into the region of Ordovician clastic sediments. Because of its faulted contact with the older Paleozoic rocks, its unknown thickness and lower contact, it cannot be precisely correlated with any part of the Martinsburg Shale.

CALCAREOUS ALGAE (STROMATOLITES) IN THE UPPER CAMBRIAN

by

HENRY B. ROBERTS

The following account of calcareous algae in Bucks County was reported by Roberts (Howell, Roberts and Willard, 1950, p. 1358).

Stromatolites, long known as "*Cryptozoa*" or "Calcareous algae," are an ubiquitous feature of the Upper Cambrian limestones of eastern Pennsylvania (Plates 7, 8 & 9). These fossils are often so abundant that they form biostromes, or beds of uniform thickness over wide areas, which recur rhythmically throughout most, if not all, of the Upper Cambrian sequence. Thus, in the eastern portion of the State, stromatolites were important rock-builders.

A stromatolite is a mineral copy or cast of the external form of an algal colony. It is essentially a laminated structure formed of thin films of calcium carbonate which were successively precipitated upon the surface of the growing colony. Thus, each film, or lamina, represents one of a series of growth stages, through which the colony passed. Interpreted in this way, a stromatolite is a record, preserved in rock, of the growth and development of the living plant colony that produced it.

These fossils were first noted in eastern Pennsylvania by Prime (1878) who did not, however, perceive their true nature. Walcott (1894) reported "a species of *Cryptozoön*" in the limestones near Easton. Later, Wherry (1909) recognized that cryptozoöns were characteristic of his Allentown Formation. Stose (Bascom and others, 1931) for the first time recorded stromatolites from Bucks County, and Miller (1934, 1939, 1941) published information on the local occurrence of "*Cryptozoön proliferum*" in the Lehigh Valley.

Hills (1934) noted that more than one species of stromatolites was probably present in the Lehigh Valley, and (1935) questioned the conspecificity of the Lehigh Valley forms with *Cryptozoön proliferum* Hall, to which previous authors had usually referred them. In 1937, Fenton and Fenton separated the so-called *Cryptozoön proliferum* Hall of the Lehigh Valley and Bucks County into two new species, *Anomalophycus compactus* and *Dolatophycus expansus,* and one new variety, *Cryptozoön proliferum fieldii.*

Cryptozoön fieldii and *Archaeozoön undulatum* of the Limeport Formation were the dominant builders in Dresbachian (early late Cambrian) time, while *Dolatophycus expansus* was locally abundant. During the Allentown (Trempealeauian, late, late Cambrian) cycle, the principal rock-building role was assumed by two new species of *Cryptozoön* and, to a lesser degree, by *Anomalophycus compactus.* A few reefs of the Limeport *Cryptozoön fieldii* persisted as stragglers into the Allentown.

Chapter IV

MESOZOIC ROCKS

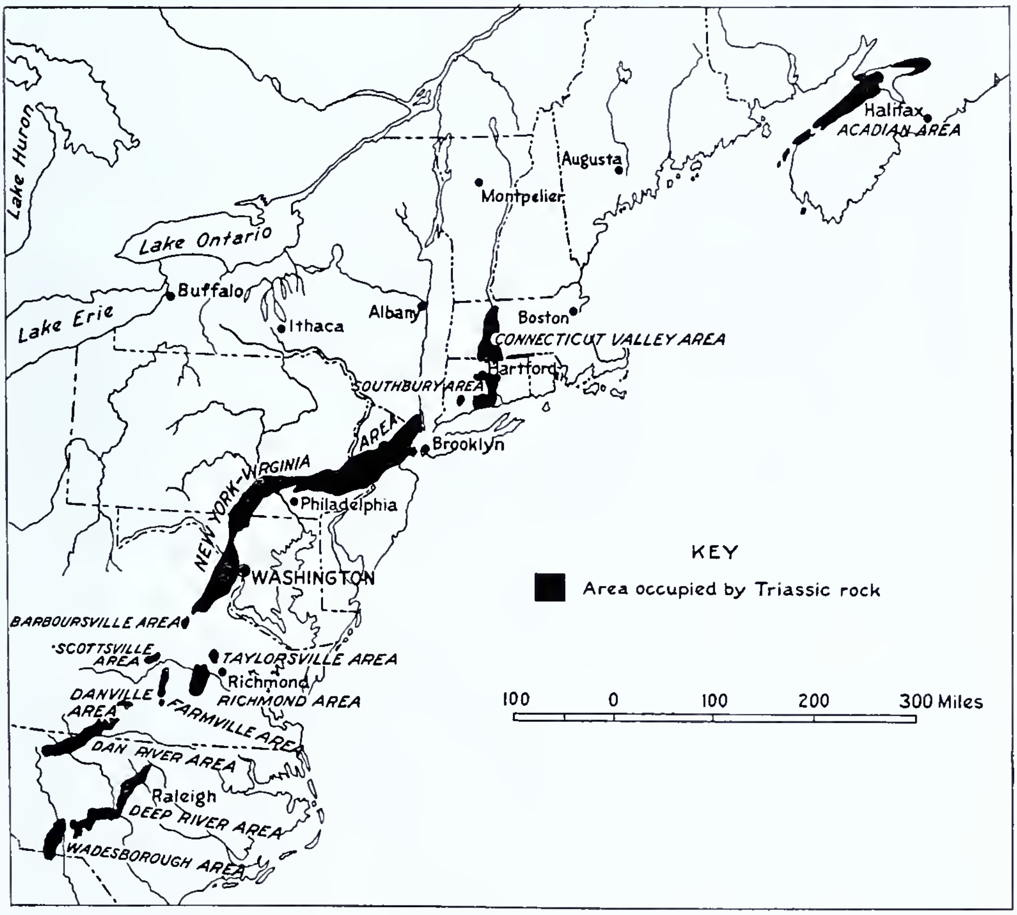
by

Dean B. McLaughlin

The Newark Group of Eastern North America

Rocks of Triassic age occur in a number of large and small separate areas near the Atlantic coast of North America from Nova Scotia to North Carolina (Fig. 6, p. 55). They have been designated as the Newark group, from Newark, New Jersey. Each area is elongated in a north-south or northeast-southwest direction. The rocks of all the regions are similar; most obviously in their prevailing reddish color. The lower part of the Newark Group commonly consists of interbedded, yellowish arkose, gray and red sandstone, with fine to coarse conglomerate near its base. The higher beds are mostly red sandstones and shales; some areas contain much red shale, others mainly red and brown sandstone. Where the higher beds adjoin older rocks, masses of coarse fanglomerate occur at many places, though not continuously, along the border. The sediments are commonly intruded by diabase or "trap

Figure 6



Map showing areas occupied by Triassic rocks in eastern North America. After I. C. Russell.

rock" sills and dikes, and in some areas thick flows of basaltic lava are interlayered with the upper strata.

At all known localities the rocks of the Newark Group are disturbed. Broad warpings have produced open synclines and anticlines. The most prevalent structures are normal faults and concurrent tilting of fault blocks in a preferred direction, such that the strike of the beds is usually roughly parallel to the long axis of the basin. In a majority of the areas the strata dip northwestward with some noteworthy, local deviations, but in the Connecticut Valley and the eastern basins of North Carolina, the dips are eastward and southeastward.

The Newark Group overlies eroded Paleozoic and Pre-Cambrian rocks with profound unconformity. The youngest underlying rocks that are seen in contact with basal strata of the Newark Group are the Pennsylvanian rocks of Nova Scotia. Elsewhere the known basement consists of Pre-Cambrian and Paleozoic rocks. In New Jersey the tilted and partly eroded Newark Group is overlapped unconformably by deposits of late Cretaceous age in the Coastal Plain Province.

In rocks of the Newark Group fossils are scarce. During the course of time, however, numerous finds have accumulated, and a few localities have yielded fairly abundant remains. In the Connecticut Valley, skeletons of a few small dinosaurs and other reptiles have been found, and footprints of land animals are widespread. Molluscs, crustaceans and fishes are known from several localities. The aquatic animals are all fresh-water forms. The plant remains include algae, rushes, ferns, cycads and conifers. Silicified wood has been found at many places. The comparative scarcity of fossils is probably due in large measure to unfavorable conditions for preservation, rather than to a scarcity of life in Triassic time.

The rocks show abundant other evidence of their continental mode of origin. The arkoses and siliceous sandstones are extensively cross-bedded, and conglomerate often occurs in lenses and as probable channel filling. Abrupt change in character of individual, coarse-grained beds along the strike is characteristic. Sandstones and shales are commonly ripple marked and mud cracked. The fanglomerates bear witness of torrential streams that brought great loads of sediment from the bordering higher lands to be distributed far and wide over the basins by shifting streams, or to slowly settle from suspension in temporary, shallow lakes. Large parts of the deposits represent merging of extensive alluvial fans.

Name, Correlation, and Age

Early literature designated the rocks of the Newark Group simply as "Mesozoic" or "New Red Sandstones." The name "Newark" was first applied to this system by W. C. Redfield (1856) but it was not adopted generally until after the sequence of formations had been worked out by H. B. Kümmel (1897) in New Jersey.

The general similarity of lithology, structure, stratigraphic relations, and fossils in all the areas of rocks of the Newark Group indicates that all were probably deposited penecontemporaneously. On the other hand, there is as yet no conclusive evidence of any kind that points to precise correlations of the various "members" or "formations" of one area with those of another. As studies of the rocks of the Newark group became increasingly detailed, it is found that there is less and less basis for expecting such correlation. The character of the deposits was strongly controlled by local environment, and the onset of similar conditions may have occurred at different times in different areas.

A possible correlation of the rocks of the Newark Group in the Connecticut Valley with those of New Jersey (which are stratigraphically continuous with the deposits in Pennsylvania) has been summarized diagrammatically by Colbert (1946, p. 267). The fish beds, both at Boonton, New Jersey, and in Connecticut, occur close to the highest of three lava flows. Equivalence of the fish beds and matching of the lavas receives some support from the stratigraphic distribution of fossil reptiles, footprints, and plants. But beneath the lowest lava the thickness of sediments in Connecticut is only about half of that in New Jersey. This is in spite of the fact that the Connecticut series is chiefly arkose, while much of the New Jersey succession is shale which probably accumulated more slowly. These circumstances suggest that sedimentation may have begun later in Connecticut.

Closely related to the problem of correlation is the problem of the former connection or lack of connection of the now discontinuous areas of Triassic rocks. These two possibilities have been designated as the "broad terrane" and "local basin" hypotheses (Russell, 1892, p. 101). A full discussion is outside the scope of this report, but a few important points may be mentioned. In the first place, sedimentation did not begin even approximately simultaneously at all localities. The rocks of the Newark Group in southeastern Pennsylvania alone afford proof of this assertion even if the correlation of beds in New Jersey and Connecticut is ruled out as inconclusive. The lowest unit, the Stockton Lithofacies, is stratigraphically continuous from southeastern Bucks County westward to northern Chester County. In Bucks County its thickness is about 3,000 feet; in Chester County, only about 1,000 feet. The thinning is due to overlap to the west, where the lower beds, followed along the strike, end against the underlying crystalline rocks. It is possible that the floor had considerable relief and that some of the hills may have been so high that they were not buried during Stockton sedimentation. In this connection the region between New Jersey and Connecticut is particularly interesting. The Southbury (Pomperaug Valley) area lies between the larger basins at distances (from the nearest points of the boundaries) of 14 miles from the Connecticut Valley and 40 miles from New Jersey. Within the Southbury area are lava flows that may be equivalent to those of the Watchung Mountains and of the Connecticut Valley. But beneath them occur less than 1,200 feet of sediments in contrast to some 12,000 feet reported in New Jersey and 6,500 feet in Connecticut (Davis, 1898 p. 28). The strike of the lower beds in northern New Jersey and southern New York runs towards the crystalline rocks across the Tappan Zee from Haverstraw, New York, in a manner that strongly suggests overlap. In all probability the floor in this area shelved up towards the northeast. If rocks of the Newark Group were ever deposited near the Connecticut-New York boundary, they were very much thinner than in the present basins and represented only the uppermost beds now found in New Jersey or Connecticut.

Existing fanglomerates show the location of the border of the basin at the time of their deposition, though in some places younger beds may have overlapped beyond the present basin limit. Fanglomerates occur intermittently all along the present northern and western border of the New York-Virginia area, and along the eastern border of the Durham and Deep River basins in North Carolina and the eastern border of the Connecticut Valley. An indication of the eastward extent of Triassic sediments beneath younger beds is given by a deep boring near Salisbury, Maryland (Richards, 1945). There, near the Atlantic shore, beneath a thick cover of Cretaceous rocks, Triassic shale and arkose were encountered at a depth of 5,360 feet. However, there is no reason to assume that these buried Triassic rocks were actually continuous with any now exposed.

In summary the evidence suggests that the rocks of the Newark Group may have been deposited in one large basin with an extremely irregular floor or, more probably, in a group of interconnected, long, narrow intermontane basins. The region had its western boundary east of Catoctin Mountain in Virginia, south and east of South Mountain and the Reading and Durham Hills in Pennsylvania, and southeast of the Highlands of New Jersey. The eastern border is only partly preserved along the eastern edges of the Connecticut Valley and of the Durham and Deep River basins of North Carolina.

Accurate correlation with the Triassic system of Europe is still somewhat uncertain. Stratigraphic relations to older and younger rocks give only a rough indication of the age as younger than Pennsylvanian and older than Cretaceous. The rocks of the Newark Group were deposited on deeply eroded Paleozoic rocks which had been folded during the Appalachian orogeny. The rocks of the Newark Group were intruded by diabase, faulted, tilted and peneplaned before the Cretaceous sea advanced upon the land.

Attempts to date the rocks of the Newark Group by means of their scarce fossils have not yielded completely accordant results. Thus, Eastman (1905 and 1911) considered the fish from the top of the series to be late Muschelkalk to early Keuper in age (late Middle Triassic), whereas Lull (1915) concluded from a study of the terrestrial vertebrates that the Newark Group might extend from the Keuper into the Jurassic. Von Huene (1921) believed that Newark deposition extended from the Muschelkalk through the Keuper and Rhaetic, ending at the close of Triassic time. Colbert (1946, p. 266) regards the uppermost beds, the Brunswick Lithofacies, in New Jersey, as of late Triassic age, but considers von Huene's views tenable in regard to the duration of sedimentation of the Newark Group. The Lockatong Lithofacies in Pennsylvania has sometimes been considered about equivalent to the "Lettenkohle," the lowest member of the Keuper (Wherry, 1912c, p. 373; and W. Bock, 1946). Recently Bock (1952) reviewed the paleontological evidence and suggested that the entire Newark Group was deposited in a very short period, equivalent to the middle Keuper. The question of correlation is still open. None of the fossils so far discovered have a sufficiently restricted range to yield conclusive results. The great thickness of the Newark Group appears to require a long period of deposition, even though these continental deposits could have accumulated much more rapidly than marine sediments. For the present, the Newark Group may be regarded as roughly equivalent to the European Keuper, that is, Upper Triassic.

A numerical estimate of the age in years is afforded by the ratio of helium to uranium and thorium in samples of the diabase intrusions and basalt flows. Urry (1936) determined ages of rocks from the Palisades of New Jersey and from two intrusives near New Haven, Connecticut. In six samples, each with a probable error of about 10 million years, these ranged from 155 to 175 million years in age. Two age determinations on surface lava flows are especially significant, inasmuch as those rocks solidified before the sedimentation ceased. These ages are as follows:

Basalt, Cape Spencer flow, Nova Scotia 160 ± 8 million years
Basalt, First Watchung Mtn., New Jersey 180 ± 11 million years

The agreement of all the results, from both intrusive and extrusive rock, is good, and an approximate age of 170 million years may be adopted for the upper Newark Group. There are no data that suggest an equally reliable figure for the duration of Newark time.

THE NEWARK GROUP IN BUCKS COUNTY

Rocks of the Newark Group cover about 80 percent of the area of Bucks County. They are part of the largest Triassic area of the Atlantic seaboard which extends from the west bank of the Hudson River in southeastern New York State, across New Jersey, southeastern Pennsylvania and central Maryland, into northern Virginia. In the main, the description already given for the rocks of the Newark Group applies to the New York-Virginia area, but with some unique differences. Triassic rocks are 32 miles wide in Bucks County, the widest in the belt. They are cut by unusually large normal faults that cause extensive repetition of strata. One fault brings Paleozoic rocks to the surface. In the Delaware Valley thick, hard, dark-gray to black argillite occurs. If we except red shales that have been baked to a hard gray or black hornfels near intrusive bodies, such argillite is almost unknown in other Newark Group areas.* The Triassic rocks of Bucks County and closely adjacent regions contain a larger proportion of shale to sandstone than is found in most areas. It can hardly be a coincidence that the greatest amount of gray argillite and red shale is found in the very region where the present outcrop of the Newark Group is widest. Evidently the conditions of sedimentation differed in some respects from those that prevailed in the greater portion of the Newark terrane.

Because the fault blocks are tilted to the northwest, most of the Bucks County Triassic sedimentary rocks dip in that direction between

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* A small thickness occurs on White Oak Mountain north of Danville, Virginia, and a little black shale in Connecticut, and at North Bergen, N. J.

5° and 20°. Local departures occur near the larger faults and the north border. Large-scale drag folding is evident near the great faults. Broad synclinal warpings affect the rocks in the northern and northwestern parts of Bucks County.

After repetition by the great faults is taken into account, the calculated thickness of the Newark Group is 12,000 feet or more. This figure has been doubted by some geologists. It is probably true that at no single place can that full thickness of strata be found. The floor of the basin probably shelves upward to the north, and there the uppermost beds overlap the older rocks directly. The lowest beds that appear near the southern margin may pinch out entirely some distance from the north border. Thinning of the beds towards their northern source of supply would further reduce the vertical thickness of the strata at places within a few miles of the northern edge of the basin.

Some geologists have claimed that extensive repetition of beds by faulting has caused a thickness of the order of 2,000 feet to appear like 10,000 feet or more. It is indeed true that numerous minor faults exist. E. H. Watson (personal communication) has measured many minor faults in a railroad cut at Gwynedd, Montgomery County, and has found a significant effect on the apparent thickness in that section. The increase was approximately 33 per cent, and not a multiplication of the thickness. In Bucks County, the tracing of identifiable strata for many miles, the establishment of the order of superposition by observation of all contacts, the recognition of interfingering facies by McLaughlin and Willard (1949), and the proven absence of faults in some extensive sections, leave no doubt that the thickness of the series is indeed great. It is certain that no unknown faults can account for any large fraction of the total apparent thickness. The evidence for thickness of specific formations and the details in a number of areas will be discussed below with each subdivision of the group.

Over fifty years ago, Kümmel (1897, 1898) subdivided the Newark Group of western New Jersey into three "formations"; in ascending order, the Stockton sandstone, Lockatong black argillite, and the Brunswick red shale. A fourth lithologic type, the border conglomerate, he considered a local facies of all three "formations" near the north border of the basin. The three subdivisions extend southwestward across Bucks County, and into Montgomery County. The succession in Bucks County, may be summarized as follows:

	Feet
Brunswick Lithofacies above Haycock sheet	5,000
Diabase (Haycock sheet)	1,700
Brunswick Lithofacies below Haycock sheet	3,845
Lockatong Lithofacies	3,868
Stockton Lithofacies	5,002

In the later discussion it will be seen that the three sections of strata are lithologic facies that interfinger to a greater or less extent rather than distinct, time-stratigraphic units. In any section across the strike, however, the main bodies of these three units lie one above the other in the order named. Within the limits of Bucks County there is not much interfingering of Stockton and Lockatong Lithofacies exposed, but a limited amount of it probably occurs near Rushland. In contrast, extensive interfingering and lateral gradation of Lockatong and Brunswick Lithofacies have been observed. Eastward in New Jersey the Lockatong becomes thinner before it passes under the overlying Cretaceous. Farther northeast, where the Lockatong argillite might be expected to emerge, there is only a local black shale at North Bergen. At most places the Brunswick and Stockton Lithofacies adjoin, and the Brunswick becomes sandy and conglomeratic. A similar change occurs westward; the Lockatong argillite grades along the strike into, and interfingers with, red shales of the Brunswick Lithofacies, until the gray argillite disappears completely several miles west of Phoenixville. The Brunswick shale in that direction grades into sandstone and then into coarse conglomerate that is extensively developed in southern Berks and northern Chester Counties (Bascom, 1938). McLaughlin (1939) has designated this the Robeson conglomerate. Still farther west, in Lancaster, York and Adams Counties, only two main formations have been recognized (Jonas & Stose, 1930; Stose, 1932; Stose & Jonas, 1939). These are the New Oxford sandstone and arkose, identical lithologically with the Stockton Lithofacies, and the overlying Gettysburg red shale, the approximate equivalent of the Brunswick. The Gettysburg Shale differs from the Brunswick in having the prominent Heidlersburg Sandstone member in its upper portion and great lenses of conglomerate near its base. The latter form the Conewago Hills in York County and Elizabeth Furnace Hill in Lancaster County. The New Oxford Formation and the Gettysburg Shale extend across Maryland into Virginia, where they are designated respectively the Manassas Sandstone and the Bull Run Shale (Roberts, 1928, p. 24, 38).

Fanglomerates, widely developed at the northern border of the Triassic rocks in Bucks and Lehigh Counties, and in Hunterdon County, New Jersey, to the east, interfinger with the higher shale and sandstone beds of the Brunswick Lithofacies. In New Jersey, fanglomerates also interfinger with the Lockatong and Stockton where those rocks approach the north border.

Data on the exact structural relation of the Triassic rocks to the older rocks on the north are not complete. In Bucks County the northernmost Triassic strata are 10,000 feet higher stratigraphically than the basal beds at the southern border. It has often been suggested that a profound fault marks the north border. Faults do occur at some places in that vicinity, but at others there is evidence that the Triassic fanglomerates overlap the older rocks (Wherry, 1913, 1941).

The hypothesis that seems to accord best with all the facts postulates some faulting along the north border during deposition, followed by an overlap of the later sediments to the northward which buried the fault when the basin was filled to overflowing (Stose & Jonas, 1939). Local, post-depositional movements must have occurred along faults at or near the border, for at some places the shales dip rather steeply towards the older rocks to the north. It does not appear likely that the Triassic rocks ever extended more than a few miles north of their present limit. However, in northeastern Berks County, the hill called the Spitzenberg is capped by probable Triassic conglomerate (Whitcomb and Engel 1934, and Whitcomb, 1942). This is 18 miles north of the nearest point of the main Triassic area. It is likely that the conglomerate represents the filling of a local channel, possibly the ravine of one of the torrential streams that entered the basin from the north. A less extreme case of a similar kind is a small outlier of conglomerate at Mount Paul, three miles north of Gladstone, New Jersey, and two miles from the edge of the main area of Triassic rocks (Kümmel, 1897, p. 51). This differs from the Spitzenberg, however, in that it lies in a valley that opens directly on the Triassic lowland. The valley is floored by Paleozoic shale and limestone that is faulted down between ridges of Pre-Cambrian gneiss. It is quite clear at this place that the rocks of the Newark Group formed only a thin covering over the Paleozoic rocks, though the sandstones of the main area close by are high in the Brunswick Lithofacies (Kümmel, 1898, p. 114).

The rocks of the Newark Group in Bucks County are intruded by thick sheets of diabase, by large dikes that cut across from sheet to sheet, by narrower dikes some miles in length, and by small, local dikes. One dike extends many miles southward and southwestward into the ancient crystalline rocks. Adjacent to the intrusions the red shale has been baked to a hard, brittle hornfels, and its color has been altered to dark bluish-gray, black or purple. Some of these baked shales, especially when weathered, are not easily distinguished from the argillite of the Lockatong Lithofacies. No surface flow of lava is known in Bucks County. It is practically certain that none lie buried beneath sediments within the borders of Bucks County, but it is quite possible that some did exist in the past and have been completely eroded. A small flow of basalt near Sand Brook, New Jersey, is only five miles from the nearest point of Bucks County, and flows several hundred feet thick form the Watchung Mountains farther east. An extrusive sheet is also known to the west at Jacksonwald in Berks County.

The intrusion of the sheets and dikes probably accompanied, but may also have preceded and followed, the surface outpourings of lava. Most of the igneous activity preceded the faulting and tilting of the rocks of the Newark Group. Sheets and dikes are cut off by faults at several places in Bucks County and vicinity, and nowhere in Bucks County is diabase known to occupy a fault zone. In Berks and Chester Counties, however, the great Gibraltar and Elverson dikes probably did ascend along faults (McLaughlin, 1939, p. 68; 1942, p. 468; Stose, 1938, p. 97). In Lebanon County there is some evidence of a large dike ending against an earlier fault.

Fossils have been found at several places in Bucks County and nearby areas. These are discussed on pp. 114-125. In the present sections, only brief references will be given to the fossils found in each lithofacies.

Stockton Lithofacies*

Distribution

The Stockton Lithofacies occupies two separate belts in Bucks County, the southern and the northern. The southern belt is about four miles wide at the Delaware River, with Yardley near its center, and extends west-southwest to the Montgomery County line where the width increases to six miles. The northern belt crosses the Delaware River between Center Bridge and Lumberville, where its width is about four miles, and trends southwestward with fairly constant width until it is cut off diagonally by the east-west Chalfont fault that passes through Chalfont and south of Doylestown.

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* Lithofacies is used rather than formation because of the intertonguing nature of the units which prevents drawing distinct boundaries.

Topographic Expression

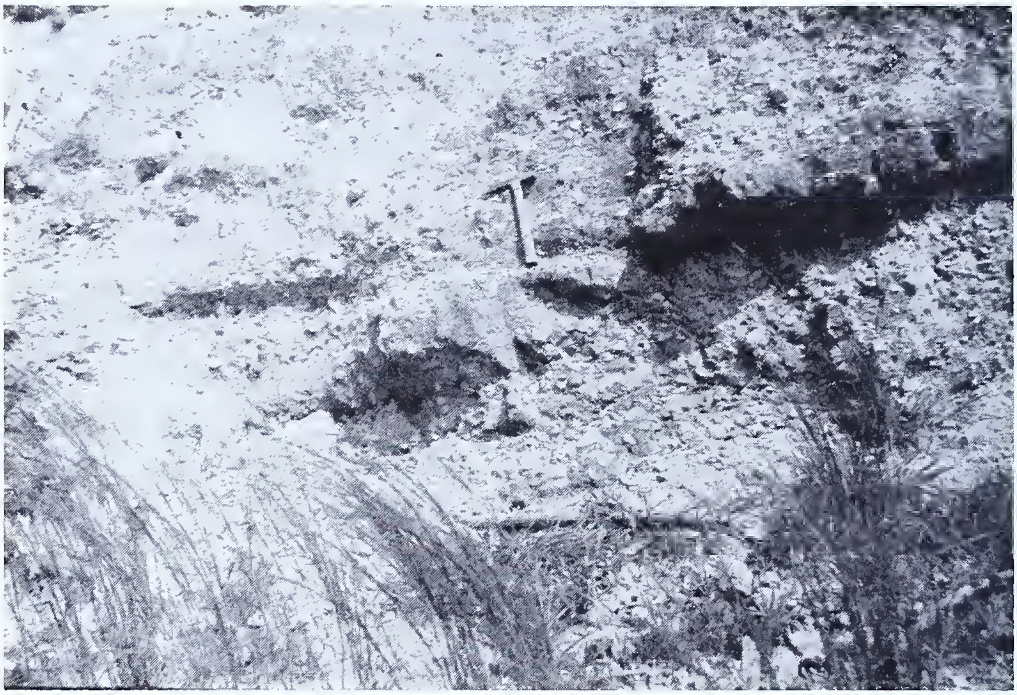
Both belts of the Stockton Lithofacies underlie low, rolling country. In the southern belt the only deep valleys are those of the Delaware River and Neshaminy Creek. Even the smaller brooks show little tendency to flow along the strike. Most of the hills have irregular shapes, with flat summits 150 to 350 feet above sea level. The valleys of the smaller streams are broad with gentle slopes. A few vague ridges trend with the strike of the beds. The northern belt has more distant ridges parallel to the strike. The general level of the hilltops is 350 to 450 feet above sea level. Most of the streams have eroded broad shallow valleys on soft red sandstone members, but resistant arkoses form the intervening ridges. Locally, streams cross the strike in narrower valleys. A distinct but discontinuous ridge marks the course of a prominent conglomerate member through Centre Hill and Spring Valley. The southeastern edge of the northern belt is a line of low hills that rises slightly above the more easily eroded Paleozoic limestones of Buckingham Valley. A ridge along the northwestern edge of the belt has sandstone of the upper part of the Stockton Lithofacies on its steep southeastern slope, but owes its prominence to the resistance of the overlying Lockatong argillite.

Lithology

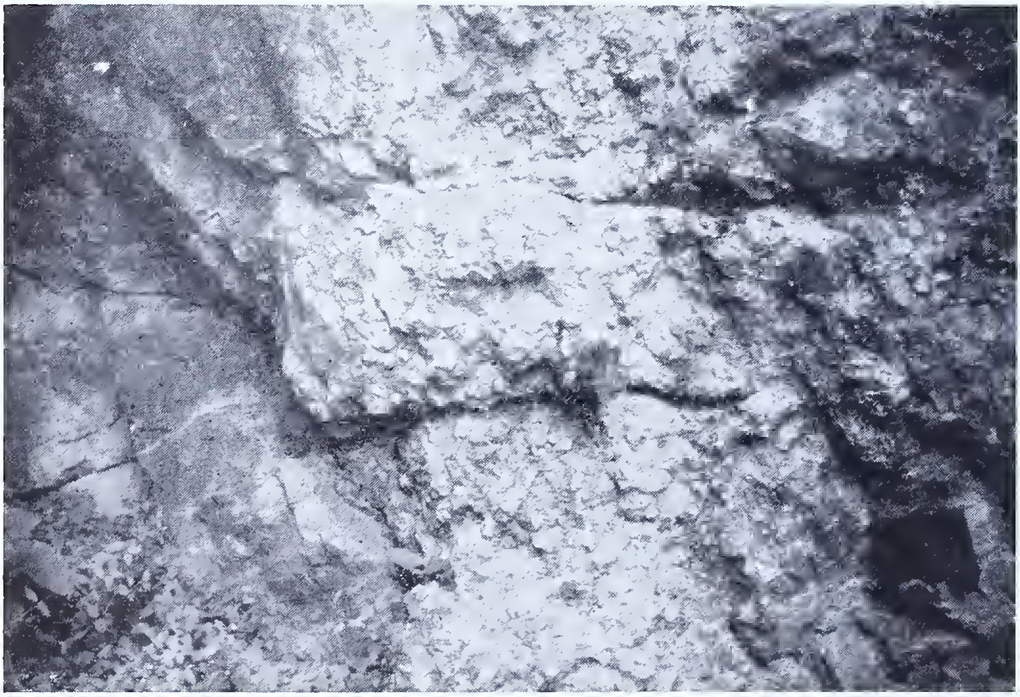
The rocks of the Stockton Lithofacies differ widely in bedding, texture and color (Plate 10, p. 64). They range from coarse conglomerate, through coarse-grained and fine-grained arkose, to fine-grained siliceous sandstone and shale. The outstanding feature of the unit is its high content of arkose. The several types of rock are interbedded throughout most of the Stockton Lithofacies, but there is almost no conglomerate in the upper half, and fine-grained sandstones are more abundant above than below the middle. Arkose occurs in considerable amounts at all horizons except in the uppermost several hundred feet.

The interbedding of the rock types varies. In a given exposure it is common to find similar beds for 20 to 50 feet of thickness, whereas in limited zones rapid alternation of different types occurs in thicknesses of several feet. A few, fairly homogeneous, thick beds of arkose or nonarkosic red sandstone are recognizable and can be mapped approximately (McLaughlin 1945, p. 103). They have not been distinguished on the geologic map of Bucks County (Plate 2, in pocket) but are shown for a part of the area in Figure 7, p. 75. Groups of beds, 200

PLATE 10



A. Quartz pebble congomerate phase of Stockton Lithofacies in road cut 1 mile southwest of Spring Valley.



B. Limestone conglomerate at base of Stockton filling a probable solution channel in Beekmantown (?) Limestone; quarry on Stover farm, three-fourths mile north of Buckingham.

feet or more in thickness, may retain the same general character for considerable distances along the strike. The thick arkose and red sandstone members can be identified at places a number of miles apart. Single beds, on the other hand, may grade along the strike from fine-grained to coarse-grained in a few yards. Cross-bedding is common. Many beds are flat lenses that pinch and swell. These structures are readily allowed for in large exposures, but on small outcrops, they may seriously affect dip readings.

The conglomerates are thick-bedded, to almost massive, and in most places show a rough banding of poorly-sorted pebbles. Locally, the bedding is lenticular on a large scale, and some conglomerates appear to fill channels. The matrix is coarse-grained, rounded and angular fragments of quartz and pink feldspar. The pebbles are dominantly white or pink quartz, with fewer white to gray quartzite, though quartzite pebbles are locally more numerous. A few pebbles of other resistant rocks are present. Diameters of the pebbles average one inch, but numerous pebbles range to three inches in diameter and a few are larger. In most beds the pebbles are moderately rounded, but at some localities near the base of the formation in the southern area an appreciable fraction is subangular. Both spheroidal and ellipsoidal pebbles of equal size may occur together. The conglomerate weathers from medium-gray to brown; when fresh it ranges from nearly white to medium-gray or dull-yellow, never red. The light-grayish to yellowish soil from weathered conglomerate is thickly strewn with white and pink pebbles. Pink or red hues in the gravelly soil are apparently due to red shale or sandstone interbedded with the conglomerate. At one locality, on the northeast-southwest road a mile south of Churchville, the base of the Stockton Lithofacies contains a greenish, micaceous greywacke derived from schist.

Locally, small deposits of limestone conglomerate occur immediately at the contact with Paleozoic limestone. At two good exposures of this rock, the limestone pebbles are fairly rounded, densely packed and rudely bedded in a weak, red shale matrix.

The arkoses are thick-bedded and in places massive, but even in the massive variety, stratification can be seen on clean, weathered surfaces. Cross-bedding, lensing, and pinch-and-swell structure are common. Gradation along the beds from fine-grained to coarse-grained can be observed in some good exposures. The coarsest conglomeratic varieties have grain sizes up to more than one-eighth inch; in the finer-grained varieties the grains are visible only with a hand lens. The finer-grained arkoses are well-banded and uniform, with angular to subangular grains. The feldspars are partly altered to kaolin. Local isolated, thin bands have sparsely scattered, well-rounded, small quartz pebbles. The rock in outcrop ranges from light- to medium-gray and light- to dark-brown. On fresh fracture it may be almost white, more commonly light-gray to yellowish or medium-gray. One fairly common variety has a faint lavender tint and is thickly sprinkled with rusty spots of pinhead size. The arkose weathers to yellowish-gray or light-tan, sandy loam, but interbedded red shales may impart a pinkish tinge.

The fine-grained sandstones range from thin- to thick-bedded and exhibit practically every gradation from arkose on the one hand to shale on the other. Pinching and swelling and flat lenticular structures occur but are less pronounced than in the conglomerates and coarse-grained arkose. Cross-bedding is sometimes observed. Although not uncommon, ripple marks are more prevalent where thin, shaly partings occur. The fine-grained sandstones show little or no variation of texture along a specific bed. Interbedding of thin- and thick-bedded varieties may be seen in most outcrops. The prevailing colors in outcrop are dark-brown and reddish-brown. Fresh fractures show uniform or finely banded structure and are medium-brown or dark-brownish-red. One fairly resistant variety, known commercially as "brownstone," occurs in moderately thick beds without conspicuous banding. Brownstone, arkose and medium-gray, fine-grained, thin-banded sandstone grade vertically into each other. Occasionally the rock is red. This is more characteristic of the thin-bedded varieties, especially in the upper part of the formation and where it is interbedded with shale. The finest grains are probably quartz colored by hematite. Most fresh fractures show numerous, tiny, glistening flakes of mica. The red sandstones weather to brownish-red, sandy loam.

The red shales of the Stockton Lithofacies are always fairly weak and are never tough argillite. They are slightly sandy and almost invariably micaceous. The mica flakes are tiny, but reflect enough light to betray their presence to the eye. Ripple marks and mud cracks are common. Bedding is uneven and the red shales break with a hackly fracture. These red shales are similar to some beds in the Brunswick Lithofacies a few miles from the north border. Some red shales occur in almost all parts of the Stockton section; some are interbedded with the red and brown siliceous sandstones, but only locally with arkose. Although the bedding is wavy a group of beds retains essentially the same thickness from point to point of a continuous exposure, except where it shows indications of local channel erosion with subsequent deposition of conglomerate or arkose. The red shales weather to form a sandy clay, the reddest of all Stockton soils.

Near the top of the Stockton Lithofacies occur a few thin beds of dark, greenish or gray to black shale. So far as observed, these are somewhat similar to, but usually weaker than the black shales interbedded with the argillite of the Lockatong Lithofacies. At a locality near Carversville these black shales are very thick and contain a number of plant fossils.

Petrographic Analyses

Petrographic analyses of three specimens of Stockton arkose, one of which was collected from the metamorphic zone near a diabase dike, were carried out by Ryan (1948).

TABLE 12. *Petrographic Analyses of Arkose from Stockton Lithofacies*

Constituents	*Locality S1*	*Locality S2*	*Locality S3*
Quartz	55.6%	61.1%	55.9%
Orthoclase (including kaolin)	36.9	31.7	27.9
Labradorite	6.5	6.6	6.7
Limonite and hematite	1.0	0.6	..
Alteration products	..	..	9.5
Black pigment	..	..	trace

Locality S1 Center Bridge
S2 One-half mile southeast of Center Bridge
S3 One mile south of Lumberville

Remarks:

Localities S1 and S2: All grains subangular.
Orthoclase partly altered to kaolin.

Locality S3: Specimen collected near a diabase dike.
Limonite and hematite probably reduced to black, ferrous iron. Feldspars subrounded, quartz subangular. Alteration products are cordierite, hornblende, chlorite.

Gerhard (1952) carried out a petrologic study of Newark rocks from numerous localities in eastern Pennsylvania. Although the majority of samples were taken from localities west of Bucks County, a number of specimens of rocks from the Stockton Lithofacies were collected in Bucks County, and several more from localities sufficiently nearby to be of interest. Thin sections of specimens from several of these localities were studied in detail. Mineral compositions were determined with an integrating stage. The results, expressed as percentages, are shown in Table 13 (p. 68). For comparison, the last line of Table 13 gives averages of five sections of Gettysburg (Brunswick) sandstone and "subgraywacke"* from the Lebanon-Lancaster area.

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* Because of wide disagreement of definition, the word *graywacke* is still ambiguous. *Subgraywacke* is not fully accepted. Pettijohn (1949), p. 255, states, "This is a graywacke-like arenite which differs in several important respects from true graywacke. (1) It is marked by a scarcity of feldspar: only 1 to 15 percent of feldspar. Accordingly also, subgraywacke has more and better rounded quartz than typical graywacke, in which quartz actually may be subordinate to the feldspar. (2) Subgraywacke is associated with both orthoquartzite and limestones and is not found with either greenstones or chert." The introduction of the term in this report is not to be construed as official recognition by the Pennsylvania Topographic and Geologic Survey.

TABLE 13. *Mineralogical Analyses of Sedimentary Rocks of Stockton Lithofacies*

									QUARTZ FRACTION			
No.	*Lithofacies*	*Rock Type*	*Quartz*	*Feld-spar*	*Rock Frag-ments*	*Acces-sory*	*Matrix*	*Cement*	*Average Size mm*	*Sort-ing*	*Size Classes*[y]	*Average Round-ness*
46	Stockton	Subarkose*	67%	14%	4%	5%	8%	2%	0.9	poor	8	0.25
48	"	Arkose	51	32	3	2	4	8	0.9	poor	8	0.2
49	"	Subarkose	48	15	4	11	20	2	0.5	poor	7	0.25
51	"	Subarkose	64	14	3	2	14	3	0.7	poor	7	0.2
53	"	Quartzose sandstone	65	0	3	6	21	5	0.3	fair	4	0.3
54	"	Arkosic conglomerate	53	32	6	2	2	5	3.0	poor	7	..
75	"	Arkosic siltstone	52	27	3	10	8	.	0.13	fair	6	0.3
76	"	Arkose	51	28	7	2	3	9	0.06	fair	5	0.2
**	Gettysburg (Brunswick)	Sandstone and "subgraywacke"	63	2	17	2	11	5	0.5[x]	fair	6	0.4

* Term, not in general use, signifies a feldspathic sandstone with 10-25 percent feldspar. Arkose is arbitrarily defined as a feldspathic sandstone with minimum of 25% feldspar.

** Average of 5 samples from Lebanon-Lancaster area, west of Bucks County.

[x] Average of 3 samples. [y] Udden classification.

Localities: (Numbers are those given in Gerhard's (1952) report).

45.	One and one-half miles south of Phoenixville, Chester County.
46-50.	Section along Reading R.R. from Valley Forge northwest to Perkiomen Junction (numbered in ascending order).
51-54.	Section along Reading R.R. for one-half mile east of Valley Forge (numbered in ascending order).
46-57.	Conglomerate ridge near Centre Hill (Solebury P.O.), Bucks County.
58-59.	Stockton, New Jersey.
62-63.	Two miles and one mile west of Center Bridge, along River Road (Penna. Hwy. No. 32), Bucks County.
64-65.	Bend of Neshaminy Creek north of Langhorne, Bucks County.
75-76.	Quarry at Grenoble, Bucks County.

With a single exception, all the specimens of rocks from the Stockton Lithofacies are sufficiently feldspathic to be classified as subarkose or arkose. The exception is No. 53, which contains no appreciable feldspar. The locality is at the foot of the prominent ridge of Cambrian quartzite at Valley Forge, and the sample is probably composed wholly of detritus from the quartzite, though overlying and underlying beds are rich in feldspar. Aside from such local exceptions, the high feldspar content of Stockton rocks is diagnostic.

The mineral composition is as follows (Gerhard, 1952):

> The detrital quartz grains are angular to subrounded, and their sorting is poor (7 Udden size classes). Besides quartz, the 'subarkoses'* contain orthoclase, microcline, microperthite, perthite, albite, oligoclase, schist and gneiss rock fragments, muscovite, biotite, chlorite, sericite, kaolinite, illite, chlorite-sericite 'paste', ('authigenic quartz, feldspar and calcite') and accessory heavy minerals. The matrix of the samples examined ranges through a mixture of hematite or hydrohematite (turgite) and kaolinite-illite, a mixture of chlorite, sericite, and pulverized quartz grains, to finely divided sericite. A single sample never contains mixtures of these matrix end-members. Present in the same rock, however, were chemical cements, including authigenic quartz, authigenic feldspar, and carbonates; secondary quartz overgrowths are the most common chemical cement.

From numerous heavy mineral analyses (Gerhard, 1952), exact frequency counts, reduced to percentages, are given in Table 14 (p. 70) for Stockton localities in and near Bucks County. For comparison, the last column of the table contains the average of 15 samples from a thick sequence of Gettysburg sandstone and conglomerate on Hammer Creek, Lebanon County.

At the foot of Table 14 (p. 70) the percentages are grouped into three assemblages or mineral suites, according to the following scheme:

1. Reworked Sedimentary Suite
   - Round and worn tourmaline
   - Round zircon
   - Round rutile
   - Round monazite
2. Salic Igneous and Pegmatitic Suite
   - Angular and euhedral tourmaline
   - Angular and worn zircon
   - Apatite
   - Magnetite
   - Sphene
3. Metamorphic and Mafic Igneous Suite
   - Sillimanite
   - Epidote
   - Garnet
   - Blue-green hornblende
   - Anatase
   - Ilmenite
   - Worn and angular rutile

It is seen that the heavy minerals of the Stockton Lithofacies indicate overwhelmingly an origin from salic igneous and pegmatitic rocks and, in a few cases, from metamorphic and mafic igneous rocks. Both types are widely exposed south of the present Triassic belt, and they un-

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* Footnote, p. 68 on use of subarkose. Actually, the composition here give approaches more nearly a conventional graywacke.

TABLE 14. *Percentages of Heavy Mineral Types from Stockton Lithofacies*

SAMPLE NUMBER	45	46	47	48	49	50	51	52	53	54	56	57	58	59	62	63	64	65	1-16*
Round and worn tourmaline																			15
Angular tourmaline	11	22	3	3	4	18	51	38	40	24	21	3	1	2			35	38	9
Tourmaline total	11	22	3	3	4	18	51	38	40	24	21	3	1	2			35	38	24
Round zircon	13					4	3	2	3	5	2	2	2	2	5	4		1	20
Worn and angular zircon	54	24		9	6	59	32	45	32	53	11	15	20	24	29	19	25	15	49
Zircon total	67	24		9	6	63	35	47	35	58	13	17	22	26	34	23	25	16	69
Round rutile																			1
Worn and angular rutile	6	5	1	1	2	7	5	8	7	3	2	2	2	2	4	3	6	5	4
Rutile total	6	5	1	1	2	7	5	8	7	3	2	2	2	2	4	3	6	5	5
Garnet	12	41	2	18													x		x
Anatase	2	4		2	14		x			5	x	3	1	1		24	34	16	x
Apatite							x							x					x
Chlorite			x			x													x
Diopside						4	1			2									x
Epidote			80	1	50	4	1			3									
Green hornblende										1	1								
Monazite	1					8	5	7	2	1				2				x	1
Sillimanite	1	1	3		2		1		x									24	x
Sphene	x						2										x		
OPAQUES																			
Ilmenite			3	x	19														
Leucoxene			x	x	x														
Magnetite	x	3	8	63	3	x		x	16	3	63	75	74	67	62	50	x		x
Pyrite																	1		
REWORKED SEDIMENTARY	14					12	7	9	5	6	2	2	2	4	5	4		1	37
SALIC IGNEOUS & PEGMATITIC	77	90	13	96	13	77	86	83	88	82	95	93	95	93	91	69	60	55	58
METAMORPHIC & MAFIC IGNEOUS	9	10	87	4	87	11	7	8	7	12	3	5	3	3	4	27	40	44	5

x. Very small percentage.

* Average of 15 samples (No. 2 omitted).

doubtedly furnished the greater part of the Stockton sediments. It is noteworthy that the two specimens, 47 and 49, (Table 14, p. 70) in which the metamorphic and mafic igneous suite dominates were collected very close to existing outcrops of Pre-Cambrian gabbro or gabbro-gneiss. Samples 64 and 65, from near Langhorne, also contain high percentages of the metamorphic and mafic igneous suite, and Pre-Cambrian gabbro-gneiss occurs within a fraction of a mile to the south of their localities. These few cases, though certainly not conclusive in themselves, strongly suggest very short distances of transportation.

The heavy minerals of the Stockton Lithofacies contrast strongly with those of the Gettysburg (Brunswick) sandstones in Lebanon County. The latter show a high percentage of the "reworked sedimentary suite" (which is rare in the Stockton Lithofacies) and somewhat less than the content of the salic igneous suite of the Stockton Lithofacies.

Dellwig (1948) made pebble counts at a number of localities in Bucks County and neighboring areas (Fig. 10 p. 89). An approximation of the shapes of the pebbles is tabulated in Table 15 (p. 71).

Table 15. *Pebble Shapes of Conglomerates of Stockton Lithofacies*

	Locs. AI.III, V	*Locs. AII,IV, VI*	*Loc. BI*	*Loc. BII*	*Loc. BIII*	*Locs. BIV,V*
Quartz						
irregular, angular	..	..	..	24%	..	44%
discoidal, rounded	14%	10%	19%	16	4%	3
spheroidal, rounded	31	56	40	30	44	28
Quartzite						
irregular, angular	..	..	..	6	..	5
discoidal, rounded	24	15	21	14	6	5
spheroidal, rounded	23	13	18	4	13	4
Arkose*	1	..	2	..	21	..
Peters Creek schist*	0	0	0	5	3	3
Miscellaneous*	7	6	0	1	9	8

* Various shapes and degrees of rounding.

Locality	AI.	Pools Corner one and one-quarter miles east of Doylestown.
Locality	AII.	Road cut one mile northwest of Furlong.
Locality	AIII.	Road cut 0.8 mile northwest of Lahaska.
Locality	AIV.	Road junction 0.5 mile southwest of Center Hill.
Locality	AV.	Cross-roads one mile southeast of Peters Corner.
Locality	AVI.	Type locality, southeast edge of Stockton, New Jersey.
Locality	BI.	Reading R.R. cut at Yardley.
Locality	BII.	Cut on Pennsylvania R.R. 1.6 miles northeast of Whitemarsh, Montgomery County.
Locality	BIII.	Bridge 0.9 mile east of Port Kennedy, Montgomery County.
Locality	BIV.	Road cut 1.5 miles west of Valley Forge, Chester County.
Locality	BV.	Crest of hill 0.7 mile west of Valley Forge, Chester County.

At all Bucks County localities, spheroidal pebbles outnumber discoidal, and none is classified as angular. The Yardley locality, BI, is typical, with quartz in excess of quartzite and spheroidal pebbles more numerous. The first group of localities, AI, III, and V, are exceptional in having quartzite nearly equal in amount to quartz. It may be significant that these are all on the main conglomerate ridge and are not far from the present outcrop of Chickies Quartzite on Buckingham Mountain. That rock may have been exposed to erosion in the early stages of Stockton sedimentation. Of the next group, locality AII is near the base of the formation and may have been deposited when the Chickies Quartzite exposure was small, whereas localities AIV and AVI are farther from the hypothetical Chickies Quartzite outcrop. In all three, AII, AIV and AVI, the more durable quartz pebbles would survive transportation over a greater distance than Chickies Quartzite.

The counts at localities along the southern border of Triassic rocks west of Bucks County suggest the source of the sediments for the Stockton Lithofacies. All contain Peters Creek Schist pebbles which must have come from the south or southwest. Angular pebbles are abundant at all except locality BIII, which shows an excess of spheroidal quartz pebbles. The conglomerate at that place (east of Port Kennedy) overlies limestone, and the pebbles must have been transported far. Conversely, localities BII (Whitemarsh) and BIV and BV (Valley Forge) are close to steep Chickies Quartzite ridges at the foot of which angular fragments probably accumulated with relatively little transportation.

Columnar Sections and Thickness

The only large, well-exposed section of the Stockton Lithofacies in Bucks County is in the northern outcrop belt along the Delaware River from southeast of Center Bridge to Lumberville. Even there, long intervals are covered, but fortunately most parts of the section that are poorly-exposed in Pennsylvania are well-exposed along the bank of the Delaware River in New Jersey. Although individual beds change within a short distance, groups of beds that retain the same general character for several miles can be followed across the Delaware River.

The thicknesses were computed on the basis of numerous accordant dip measurements supplemented wherever possible by vertical sections in quarries, ravines or bluffs. The indicated total thickness of about 5,000 feet is believed to be not greatly in excess of the true thickness. Small, undiscovered, strike faults may have caused minor duplication, but a large percentage of repetition is ruled out by the continuity of thick conglomerate, arkose and red sandstone members for miles along the strike. That a group of faults could produce an illusory great thickness without betraying their presence by offsets or cutting out of some of the members is quite improbable. The long exposures on each bank of the river are good. Faulting has not been found along the Pennsylvania bank of the river, although faults exist near the top of the section at Carversville. In New Jersey some shearing noted in a ravine north of a point opposite Lumberville close to the top of the section of Stockton Lithofacies may represent the dying out of the fault zone at Carversville. A fault is exposed in the bed of Wickecheoke Creek in New Jersey north of Center Bridge. Its displacement is small, for, although it is diagonal to the strike, it produces no appreciable displacement of thick members.

The exposures in the southern belt of the Stockton Lithofacies are so meager that no detailed section can be determined. The thickest

TABLE 16. *Composite Stratigraphic Section, Northern Belt of Stockton Lithofacies, along the Delaware River*

Argillite of Lockatong Lithofacies	*Thickness in feet*
Reddish-brown and gray, tough, fine-grained, micaceous sandstone[*] and red shale	202
Covered; largely red, fine-grained sandstone and shale	129
Shaly, reddish-brown, fine-grained sandstone and red shale	167
Massive, medium-grained, gray arkose	30
Thin- and thick-bedded, red and brown, fine-grained sandstone	196
Massive, white and gray, medium- and coarse-grained arkose	143
Covered; fragments of fine- and coarse-grained arkose	150
Covered; fragments of red and gray, very fine-grained sandstone	350
Red shale and red, weak, fine-grained sandstone	130
Greenish-gray shale	2
Thick-bedded, gray medium-grained arkose and red sandstone	60
Thin-bedded, brown, very fine-grained sandstone and red shale	40
Massive, gray, coarse-grained arkose	5
Covered; upper part medium-grained arkose; lower, red sandstone	52
Red, weak, fine-grained sandstone and red shale	148
Massive, gray, medium- and coarse-grained arkose, with a few beds of brown, tough, fine-grained sandstone	160
Thick-bedded, reddish-brown, very fine-grained sandstone	42
Massive, light-gray, coarse-grained arkose	30
Thick-bedded, reddish-brown, very fine-grained sandstone	47
Red shale and red, weak sandstone	15
Massive, gray, medium-grained arkose	25
Covered; chiefly red sandstone and red shale	70
Thin- and thick-bedded, red, fine-grained sandstone and red shale	157
Covered; red, fine-grained sandstone above; arkose below	59
White, coarse-grained arkose, poorly exposed	40
Thick-bedded, reddish-brown, fine-grained sandstone	28
Thick-bedded, gray, medium- to coarse-grained arkose with some quartz conglomerate and interbedded red, fine-grained sandstone	137
Red, fine-grained sandstone, poorly exposed	110
Red and brown, very fine-grained sandstone and red shale	26
Thick-bedded, white and gray, coarse-grained arkose, with some conglomerate and much red, fine-grained sandstone and red shale	243
Yellow, coarse-grained arkose and quartz conglomerate	15
Thick-bedded, gray arkose with interbedded brown, fine-grained sandstone	216
Red, weak, fine-grained sandstone with some arkose, poorly exposed	447
Thick-bedded, gray, medium-grained arkose	30
Thick-bedded, white and gray arkose and quartz conglomerate	136
Covered	58
Thick-bedded, gray, coarse-grained, quartz conglomerate	20
Red shale and red, weak sandstone	58
Covered	136
Massive white and gray, very coarse-grained, quartz-arkose conglomerate	173
Interbedded gray and white, coarse-grained arkose, quartz conglomerate, red, fine-grained sandstone, red shale, intermittently exposed	720
Paleozoic limestone	
Total	5,002

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[*] Sandstone is here used to designate silicarenite as distinguished from arkose.

conglomerate member is closer to the base of the unit than in the northern belt. But the southern belt contains conspicuous lenses of conglomerate at higher stratigraphic levels. There is a distinctly greater percentage of arkose and a smaller percentage of red sandstone in the southern than in the northern belt. At the top of the section, as in the northern belt, there is a considerable thickness of red sandstone with little arkose. Enough dips have been measured to show that the average is about 8° NW. This leads to a computed thickness of 3,030 feet of Stockton Lithofacies in the southern belt. Even an average dip of 10° would give a thickness of only 3,700 feet. These figures are so much less than the 5,000 feet for the northern belt that the difference is regarded as significant. Thinning suggests onlap southward and supports the hypothesis of onlap towards a southern provenance.

Within the limits of Bucks County, no systematic change of thickness in either belt is demonstrable. Local variations are evident in the northern belt, probably due mainly to the irregularity of the floor on which the beds were deposited. The southern belt thins westward beyond Bucks County to a minimum of about 1,000 feet in northern Chester County.

Subdivision into Members

The thick arkoses, red sandstones, and conglomerate have been followed for a number of miles along the strike in the northern belt (Fig. 7, p. 75). In the southern belt, only the conglomerate near the base and the thick red sandstone at the top are sufficiently defined to be traced through a region of such scarce exposures. For the northern belt the section is summarized in Table 17 (p. 74). The first column lists thicknesses of members in the Delaware River section; the second column, thicknesses of the same members in a section through Doylestown and Bennetts Corner. The average dip in this latter section, 12° NW, leads to a computed total thickness of close to 5,000 feet, and the tabulated values have been adjusted to an assumed total of exactly that amount. This section contains less red sandstone than that on the Delaware River. At the same time, the lower members are proportionally thicker, although the total thicknesses are the same for both sections. These differences suggest a southern or southwestern source of the materials of the arkoses and conglomerates, and a northern source of the red sediments, which resemble the shales and sandstones of the Brunswick Lithofacies.

TABLE 17. *Stratigraphic Section of Northern Belt of Stockton Lithofacies*

*Member**	*Delaware River (N.E.)*	*Doylestown (S.W.)*
Upper red sandstone member	724 feet	600 feet
Raven Rock arkose member	293	350
Red and gray, fine-grained sandstone and shale	787	200
Cuttalossa arkose	232	400
Red shale and sandstone	373	150
Upper Prallsville arkose	205	200
Red sandstone	136	150
Lower Prallsville arkose	474	500
Red sandstone	447	100
Arkose with some conglomerate	224	650
Quartz conglomerate and arkose	387	700
Arkose, red shale and sandstone	720	1,000
Totals	5,002	5,000

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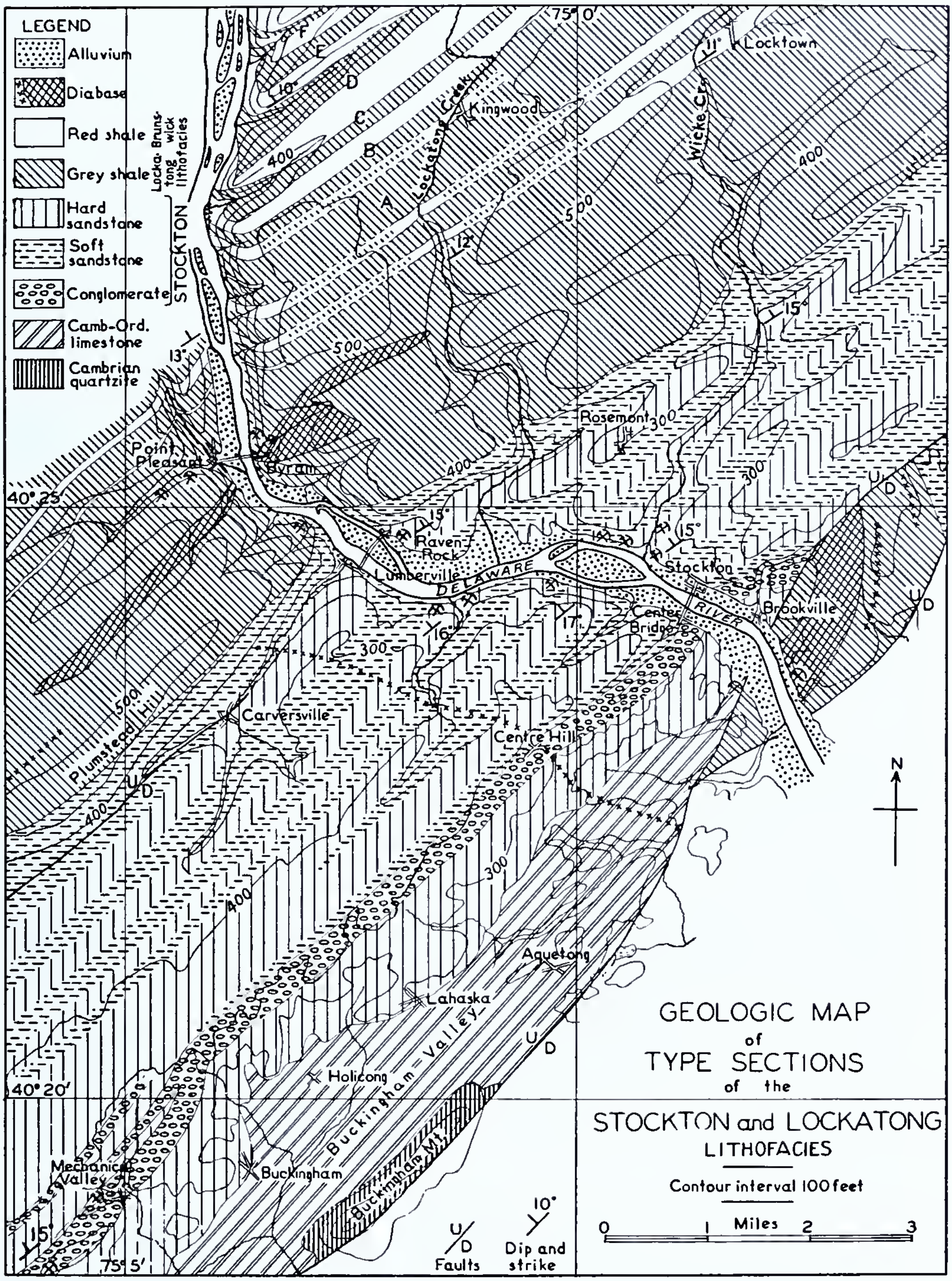
*Local names proposed originally in various papers by Dean B. McLaughlin.

FIGURE 7



Type localities of Stockton and Lockatong Lithofacies of Newark Group. Areas of "hard sandstone" are chiefly arkose; "soft sandstone" is chiefly red sandstone and shale.

Fossils

Except for part of the lower jaw of a large amphibian found in red shale near the base of the Stockton Lithofacies (Sinclair, 1917) one-quarter mile northwest of Holicong, all of the fossils found in the Stockton Lithofacies of Bucks County were plants (Wherry, 1931).

Name and Correlation

In the earlier literature the "Mesozoic" or "New Red Sandstones" were not subdivided. In the report of the Second Geological Survey of Pennsylvania the name "Norristown" was applied by B. S. Lyman (1895) to arkoses and sandstones that are the equivalent of the Stockton Lithofacies. The name "Stockton" was assigned by Kümmel (1897, p. 35, 1898) for the borough of Stockton, New Jersey, opposite Center Bridge in Bucks County. The northern band of Stockton sediments in Pennsylvania is stratigraphically continuous with the type locality. It is also continuous with and lithologically similar to the New Oxford "formation" in the Gettysburg district and is probably largely contemporaneous with it. However, the westward disappearance of the overlying Lockatong Lithofacies leaves precise equivalence uncertain. Two species of molluscs are common to the upper part of the Stockton of neighboring Montgomery County and the upper New Oxford "formation" of York County (Lewis, 1884).

Correlation with other Newark areas cannot be made with any confidence. The Stockton sediments are closely similar to the Sugarloaf arkose (Emerson, 1917, p. 93), the lowest member of the Newark Group in Massachusetts. This in turn is stratigraphically continuous with Davis's "lower sandstones," a thick series of similar arkoses in Connecticut (Davis, 1898, p. 28). Lithologic character alone, however, is of little value for correlating these continental deposits, for it implies only similar conditions of formation. If the lava flows and the fish-beds in the upper Brunswick red beds of New Jersey are the equivalent of the lavas and fish-beds near the top of the group in Connecticut, then the Connecticut arkose may be younger than the Stockton. Similar arkose makes up the lower portion of the rocks of Newark Group in the Durham basin and the Wadesboro area of North Carolina but equivalence has not been demonstrated.

Correlation with the European Triassic, still problematical, is indicated in Table 29, (Chapter IV, p. 107), and is discussed by Wherry (Chapter IV, p. 114). A tentative correlation for several areas of rocks of Newark Group is given in Table 29 (p.107). See also Reeside, et al. (1957).

Stratigraphic Relations

The Stockton Lithofacies overlies Pre-Cambrian and Paleozoic crystaline rocks with profound unconformity. In the southern belt it rests upon Baltimore gneiss and gabbro, and in Montgomery County the unconformity bevels Cambrian Chickies Quartzite and quartzose schist and the limestones at the north edge of Chester Valley. In the northern belt along the northwest side of Buckingham Valley, Stockton sediments lie in some places on Cambrian Conococheague (Limeport) Limestone, and at other places on Ordovician Beekmantown (?) Limestone. At Furlong they overlie Ordovician Cocalico (?) Phyllite. The irregular trace of the contact is at least partly due to irregularity of the floor on which the sediments were deposited. Inasmuch as the beds dip 16° NW. in Stockton exposures near Center Bridge, whereas the underlying Conococheague (Limeport) Limestone at the Limeport quarry dips 32° NW., there is an appreciable angular unconformity.

The Stockton Lithofacies of the southern belt thins conspicuously in Montgomery and Chester Counties, owing to its westward overlap onto the crystalline rocks. The westward strike of the beds trends into the crystalline rocks. This relationship is visible in miniature in a quarry at Port Kennedy, Montgomery County, where the base of Stockton section is exposed in contact with Paleozoic limestone. The lowest beds are overlapped westward. The Stockton several miles farther west at Coventryville, Chester County, is only about 1.000 feet thick. Evidently the Honeybrook upland to the south was above the level of sedimentation during the greater part of the interval of Stockton sedimentation in Bucks County.

The Stockton Lithofacies is overlain conformably by Lockatong argillite and probably interfingers locally with the latter. At the Delaware River, however, the transition from upper red sandstone of the Stockton to Lockatong argillite is abrupt. At most localities the interbedding is not sufficiently extensive to raise doubt as to the boundary. The transition from Stockton to Lockatong is more gradual in the section along the railroad south of Rushland. and much sandstone like that of the Stockton Lithofacies occurs in the lower part of the Lockatong section along Neshaminy Creek west of Edison.

South of Yardley the tilted and eroded Stockton Lithofacies is unconformably overlain by terrace gravels of Pleistocene age.

Lockatong Lithofacies

Distribution

The main body of the Lockatong Lithofacies crops out in two wide belts that extend entirely across Bucks County. A number of bands of similar rock are interbedded with the Brunswick red beds north of each belt. The southern of the two principal belts is about one and one-half miles wide at the Delaware River midway between Yardley and Washington Crossing. Westward it widens to two and one-half miles near Wrightstown, and, south of Jamisons Corner, its southern edge bulges southward, reflecting a local decrease of dip. West of there a small anticline brings the Stockton arkose northward. and the belt of Lockatong Lithofacies trends northwestward. Although partly cut off by the Chalfont fault, a strip of argillite about one mile wide connects with the southwestward-trending band of Lockatong argillite west of the anticline of Stockton arkose. This band passes on into Montgomery County and is four miles wide at the County Line south of Chalfont. The northern belt is three miles wide at the Delaware River with its southern edge between Lumberville and Point Pleasant. It trends steadily southwestward, widening to about four miles north of Chalfont.

A large part of the band is cut out by the Chalfont fault before the Montgomery County line is reached, and the remainder is terminated by the fault farther west. The small, isolated triangular area two miles northwest of New Hope on the Delaware River is the southwestern end of a larger area in New Jersey.

Topographic Expression

The Lockatong argillite is a ridge maker. In its southern belt the hilltops are 250 to 350 feet above sea level and at many places, though not all, the southern boundary is marked by a distinct rise above the level of the Stockton terrane to the south. In the northern belt the topographic effects are even more conspicuous, for the hilltops are 500 to 650 feet above sea level, and the southern border forms a steep escarpment. On its southeast face, Plumstead Hill rises 150 to 200 feet above the belt of Stockton Lithofacies and extends continuously from Lumberville to a point west of Chalfont. In both belts, but especially the northern, the smaller streams are strongly controlled by the strike of the beds, so that a number of broad ridges trend parallel to the strike. The larger streams, Tohickon, Neshaminy and Mill Creeks, have cut deep, narrow valleys through the ridges, and the first two show some good examples of intrenched meanders.

Lithology

The lithology of the Lockatong Lithofacies (Plates 11, 12 and 13) in the Delaware River section is fairly homogeneous. It comprises black or dark-gray, thick-bedded argillites* with local thinner-bedded, black shales. Some beds of impure limestone or calcareous argillite from a few inches to several feet thick occur some hundreds of feet above the base of the Lockatong column. In the upper part of the section along the Delaware River the gray argillite is extensively interbedded with dark red argillite that is as thick-bedded and as resistant as the gray variety.

Some of the black argillite is so massively-bedded and weathers into such rounded boulders that it superficially resembles diabase. This variety, due to its uniform dense texture, breaks with a conchoidal fracture. No constituent grains can be distinguished with a hand lens, and no banding is brought out on weathered surfaces. Calcite crystals up to one-fourth of an inch in length are found locally scattered through the dense groundmass.

More commonly the argillite occurs in beds about a foot thick and ranges in shades of gray. The bedding is even. Regular, narrow banding of lighter and darker layers is often visible on weathered joint surfaces, but the rock is not fissile. Some thin beds of rather fissile black shale occur, but they are a minor element. Some beds contain numerous tiny cubes of pyrite. Ripple marks are scarce, but mud cracks can be found on some bedding surfaces in almost every large exposure.

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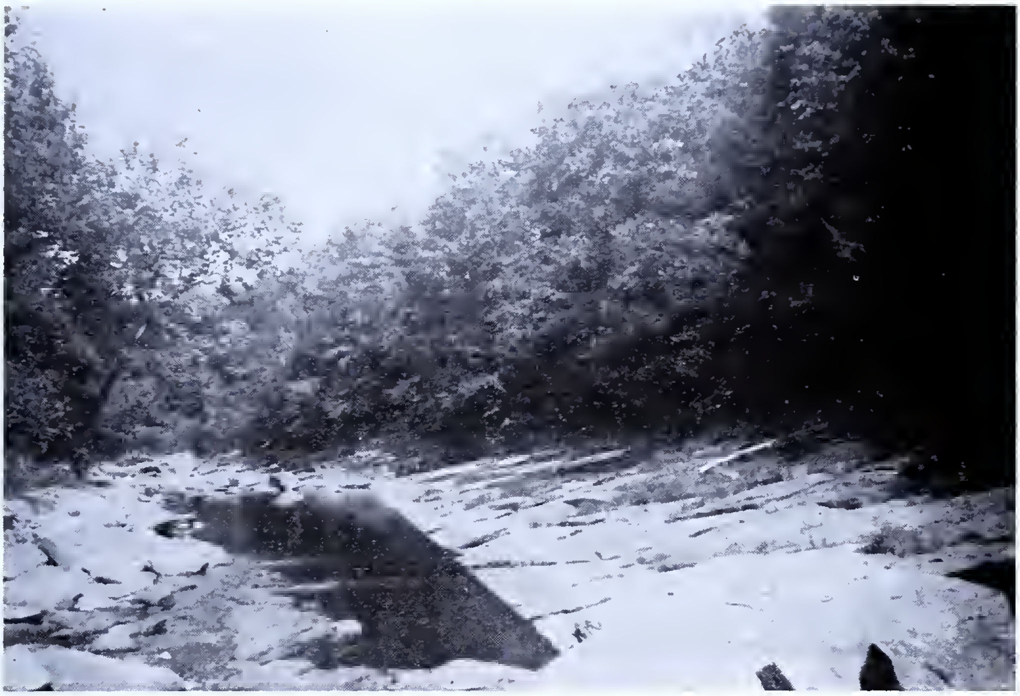
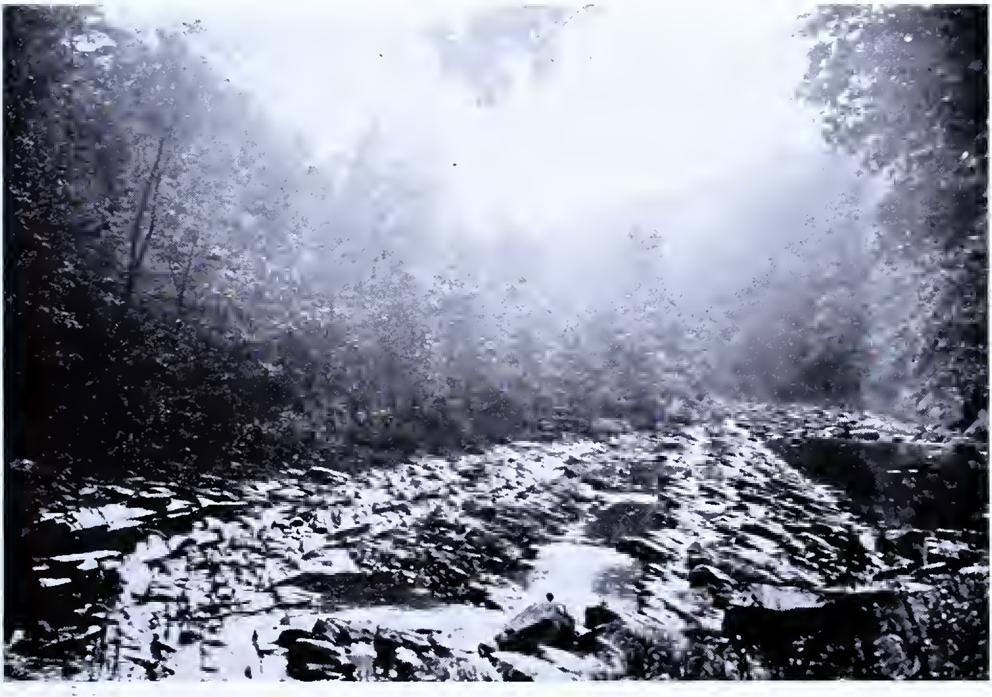
* The term argillite is used here to mean a firmly cemented, tough, argillaceous rock without fissile bedding. This term has elsewhere been used for a low grade metamorphic rock (Pettijohn, 1949, p. 269).

PLATE 11

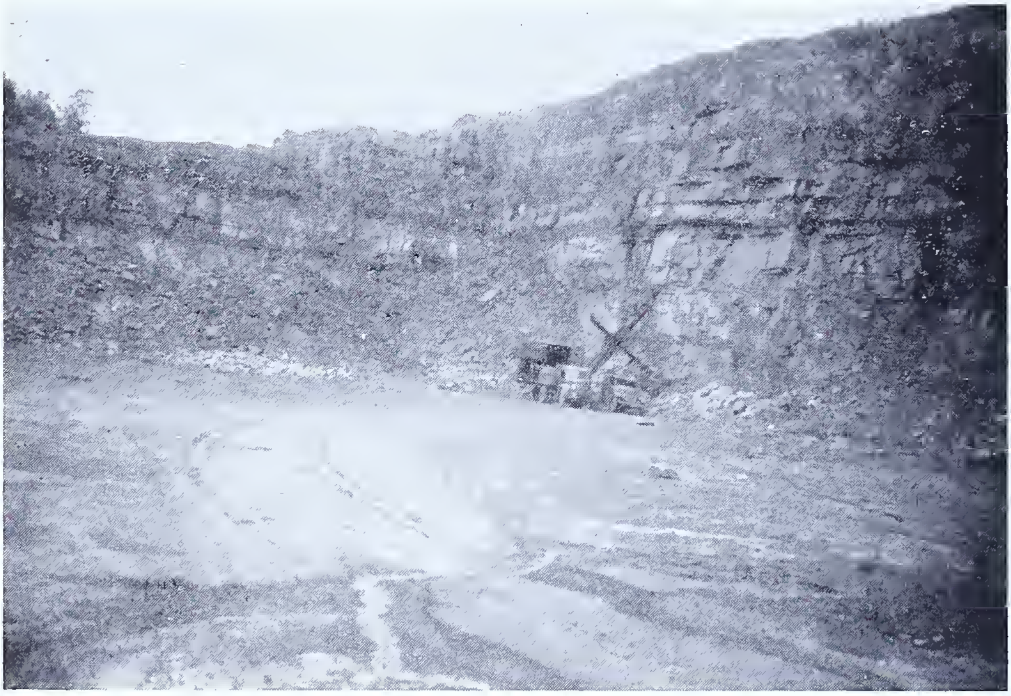


A. Argillite of Lockatong Lithofacies in Tohickon Creek, three-eights mile northeast of Ralph Stover Park.

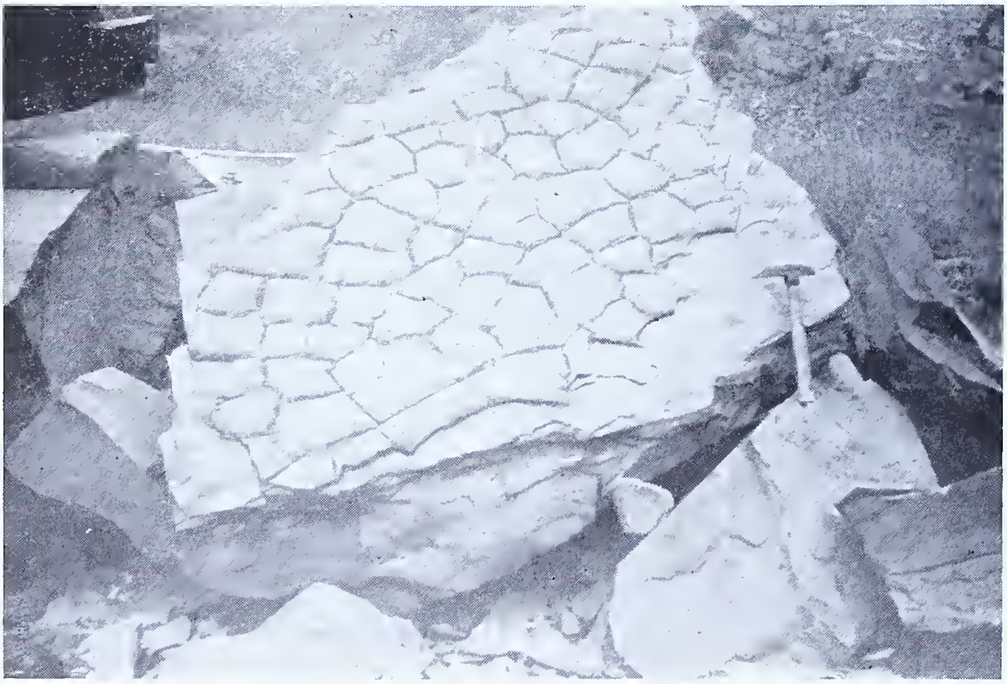


B. Argillite of Lockatong Lithofacies in Tohickon Creek, one mile northeast of Ralph Stover Park.

Plate 12

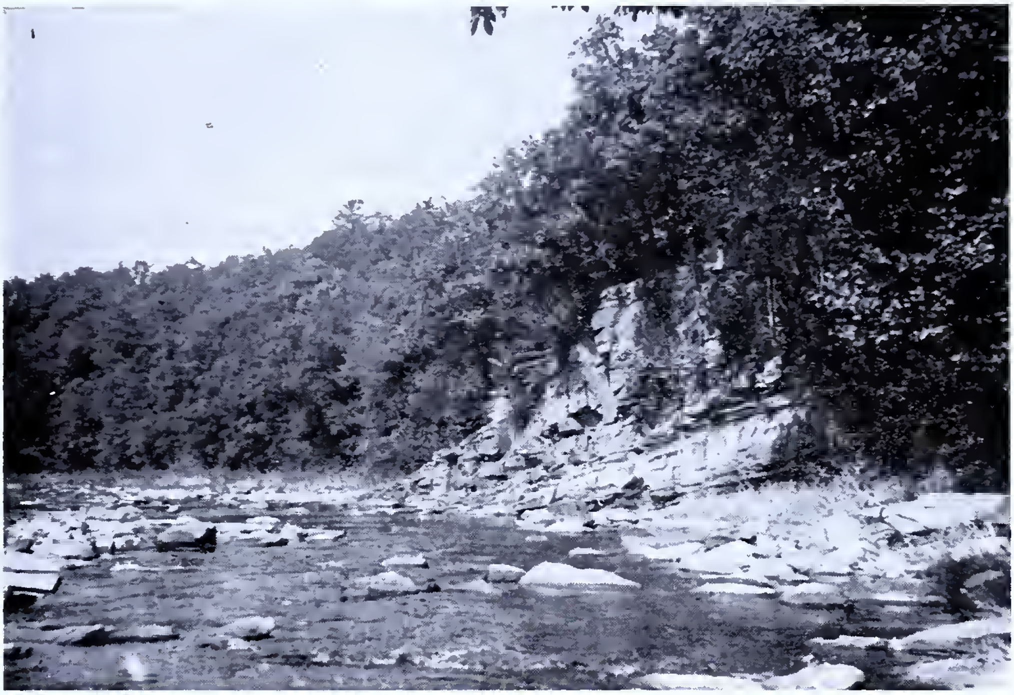


A. Gloster's quarry in black argillite and shale of Lockatong Lithofacies one mile southwest of Tradesville.



B. Mudcracks in black shale of Lockatong Lithofacies. Quarry one and one-half miles southeast of Taylorsville.

PLATE 13



A. Exposure of gray argillite and shale of Lockatong Lithofacies, Tochickon Creek, one-fourth mile east of Ralph Stover Park.

B. Quarry in Lockatong argillite, Rushland.

The calcareous beds are rendered conspicuous by their characteristic solution weathering and pitting. They are usually lighter colored than the enclosing, dark-gray argillite. Rock that is calcareous enough to be considered an argillaceous limestone occurs in beds not more than a few feet thick, between strata of hard argillite. Associated with these rocks is a considerable amount of thick-bedded, resistant, pale-gray argillite that is slightly calcareous.

The red argillites, as seen in outcrops at many places, differ from the gray chiefly in color. In addition, the bedding of some of the red rocks is thinner and less regular than that of the gray. Toward the western part of Bucks County where the red beds are more dominant, the bedding is somewhat thinner and the rock is weaker, more like typical Brunswick red shale (p. 93). A few beds of shale or argillite are chocolate-brown. Approximately 50 feet of such rock occurs in places at the top of the section that is here referred to the Lockatong Lithofacies.

Most contacts between red and gray beds are not sharp. At many places the transition occurs from red to gray or *vice versa* through an intermediate brownish- to purplish-gray, argillite or shale. The transition rock may be from a few inches to a few feet thick. At a number of places, where red overlies gray, the contact is sharp; the underlying gray is suncracked and red sediment fills the cracks. In a few beds of fine-grained, even-textured, light-blue-gray argillite, these red-filled cracks may extend several inches below the contact. Rarely there is an intraformational breccia of gray shale flakes imbedded in a dirty, reddish-brown or purplish matrix. In spite of a close examination of many contacts, no examples have been found either of mud-cracked red shale with gray filling, or of breccia of red fragments imbedded in gray. The implication evidently is that the gray shale and argillite were deposited in very quiet water, whereas the red shale represents more turbulent conditions. Where the red mud simply filled the mud cracks in the gray, a gentle flooding of a dried-out lake bed is suggested. Where the breccia occurs, the currents of flooding water were sufficiently vigorous to break up and slightly rework the dried, gray shales.

In the Delaware River section no beds in the Lockatong Lithofacies are appreciably sandy except the basal ones which are transitional from the Stockton. Near the Montgomery County line, some strata contain an admixture of fine-grained sand and silt. These are commonly associated with the red shales, but some of the gray shales also are slightly sandy and micaceous. Similar beds occur north of Rushland and in the exposures along Neshaminy Creek about a mile west of Edison.

Petrographic Analyses

Ryan (1948) carried out petrographic analyses of five specimens of Lockatong argillite, including one of red argillite and one of a transitional phase between gray and red. The results are given in Table 18.

The nature of the pigment of the Lockatong argillite from six localities has been investigated by R. E. Stevenson (1948), who analyzed

TABLE 18. *Petrographic Analyses of Argillites of Lockatong Lithofacies*

	Locality				
Constituent	*L1*	*L2*	*L3*	*L4*	*L5*
Groundmass (remarks)	99.5%	40.0%	64.0%	90.0%	93.0%
Calcite	....	35.0	29.9	5.0	5.0
Quartz	0.5	25.0	0.3	4.0	1.0
Feldspars	....	under 1%	...	1.0	...
Opal	....	....	5.8	...	1.0
Pyrite	....	trace	...	...	...
Chlorite	....	....	...	trace	...

Localities L1, L2, L3. Two miles north of Point Pleasant on Pennsylvania State Highway No. 32.

Locality L4. Point Pleasant. Locality L5. Ralph Stover Park.

Remarks:

Locality L1. Groundmass: unidentified clay minerals and black pigment. Specimen very fine-grained and homogeneous. Percentages estimated.

Locality L2. Groundmass: limonite, hematite, unidentified clay minerals, black pigment. Specimen is a gradational phase from red to black argillite. Upper, colored by limonite and hematite, changes to chocolate-brown and then black below. Microscopic sorting noticeable. Percentages estimated.

Locality L3. Red shale of Lockatong Lithofacies. Groundmass: limonite, hematite, unidentified clay minerals. Specimen taken immediately above L2 where red shale overlies black argillite. Secondary opal fills cavities.

Locality L4. Argillite of Lockatong Lithofacies. Groundmass: unidentified clay minerals, black pigment. Calcite and opal are secondary and fill cavities.* Percentages estimated.

Locality L5. Argillite of Lockatong Lithofacies. Groundmass: unidentified clay minerals, black pigment, a little limonite and magnetite. Bedding visible. Parallel to bedding are bands high in carbonate. Percentages estimated.

for ferric iron, ferrous iron and carbon. Both ferric and ferrous iron were present in all samples, the former in moderate amounts, the latter abundant. After treatment of the powdered rock with hydrofluoric acid, the residue on filtering was found in all cases to contain free carbon, but it was extremely scarce in two samples that were collected from the metamorphic zone about the Point Pleasant sheet. The pigmentation of the argillite is evidently attributable to the combined effect of ferrous iron sulfide and carbon, the latter chiefly in the form of hydrocarbons, which could be vaporized by the heat of the intrusive diabase.

Columnar sections and thickness

Along the Delaware River and Tohickon Creek the Lockatong argillite is well exposed in the northern belt from Lumberville to two miles north and northwest of Point Pleasant. The sections in Bucks County are supplemented by an excellent series of exposures on the New Jersey bank of the Delaware River. Thus, for the upper part of the Lockatong Lithofacies there are three sections which are in very close agreement. The exposures are continuous for long distances, and all important contacts have been observed. In Table 19 (p. 85), two sections are given: one for Tohickon Creek, and one for the Pennsylvania side of the Delaware River. The gray argillite members, A_1, A_2, and B are not specifically designated on the geologic map of Bucks County (Plate 2 in pocket), but may be identified from the key map, Figure 8 (p. 84).

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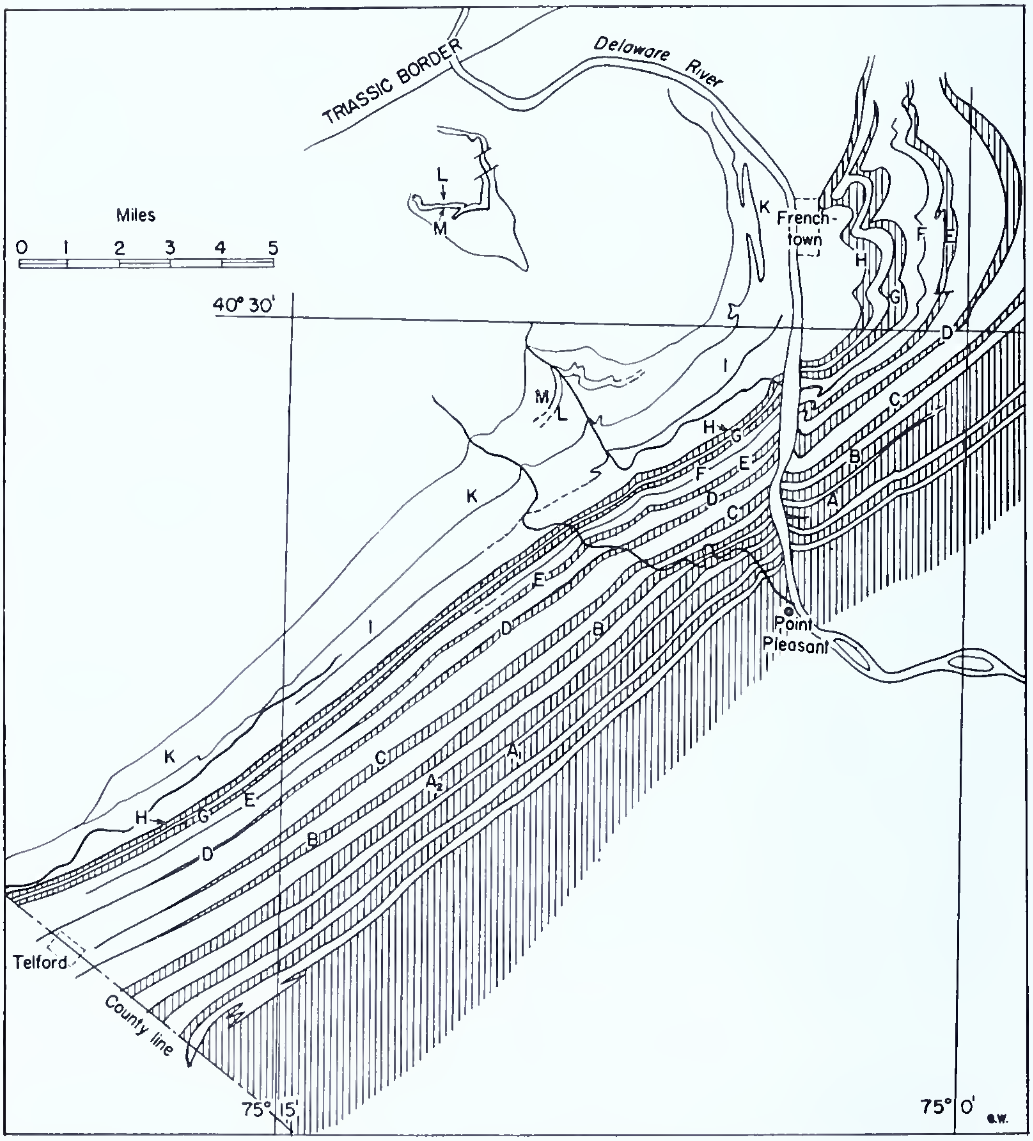
* Wherry (1931, p. 28) has pointed out that some of the calcite crystals are pseudomorphic after glauberite.

FIGURE 8



Sketch map showing Brunswick-Lockatong Lithofacies transition west of Point Pleasant. Note various members designated by capital letters but not so distinguished on the Geologic Map of Bucks County. Plate 2.

TABLE 19. *Stratigraphic Sections of the Lockatong Lithofacies along Tohickon Creek and the Delaware River*

	Tohickon Creek Feet	*Delaware River Feet*
Red shale of Brunswick Lithofacies		
Interbedded red, gray and chocolate-brown argillite	56	25
Thick-bedded, black and gray argillite "B"	190	170
Thick-bedded, red, tough argillite (upper "Double Red")	40	34
Thick-bedded, dark-gray argillite	32	29
Thick-bedded, red, tough argillite (lower "Double Red")	33	22
Thick- and medium-bedded, black argillite, with some thin-bedded black shale at base (part of A_2)	120	
Massive beds of tough, dark-gray argillite (A_2)	60	270
Thick-bedded, black argillite (lower part of A_2)	70	
Thick-bedded, red and brownish, tough argillite (Smith Corner member)	30	11
Thick-bedded, dark-gray argillite, with a few thin, calcareous beds (member A_1)	285	286
Thick-bedded, tough, red and brown argillite (upper member of "Triple Red")	24	20
Thick-bedded, dark-gray argillite	33	26
Thick-bedded, red, tough, argillite with 1 foot purplish, fissile shale (middle member of "Triple Red")	42	51
Thick-bedded, dark-gray argillite, with a little black, fissile shale	21	13
Thick-bedded, red, tough argillite (lower part of "Triple Red")	18	21
Thick-bedded, black, tough argillite	250	260
Thick-bedded, red, tough argillite, with a few thin beds of purple, fissile shale ("First Big Red")	87	100
Thick-bedded, black, tough argillite	250	276
Thick-bedded, red, tough argillite ("First Thin Red")	22	15
Thick-bedded, dark-gray, tough argillite	900	900
Thick-bedded, black, very resistant argillite (metamorphosed)		220
Diabase sill		210
Massive, black, very resistant argillite (metamorphosed)		60
Thick-bedded, black, tough argillite, intermittently exposed		300
Thick-bedded to massive, black, argillite, with much interbedded light-gray, tough, calcareous argillite, and some beds of argillaceous limestone		265
Thick-bedded, black, tough argillite, intermittently exposed		155
Medium-bedded, tough, black shale with some interbedded, brown argillite		75
Interbedded, brown, red and black, tough argillite		80
Heavy beds of dark-purplish, gray to black argillite		30
Interbedded gray, reddish-brown and red argillite		100
Thick-bedded, brownish-red, hard, sandy argillite		20
STOCKTON LITHOFACIES		
TOTAL (excluding diabase)	2,563	3,834

There is no reason to suspect significant fault repetition of strata in these sections. On the contrary, there is very clear proof that large portions of the sections are entirely free from dislocations of more than a few feet. The same argument that was presented in connection with the Stockton Lithofacies applies here with much greater force. Continuity of members along the strike for many miles rules out any large amount of duplication. Each member is fairly distinctive and would be recognized if it were repeated. Thus, there is only one "triple red" member, one "double red" member, and one thick, red argillite without any thick interbedded gray ("First Big Red" member). Even more conclusive is the continuity of thinner, red members lower in the section. The "First Thin Red" member (so-called because it is the lowest red bed recognized in the Delaware River section) is identifiable at a number of places along the strike for several miles, until it thickens to the west. Lower in the series, a red member first appears west of U. S. Route No. 611 and can be traced for eight miles southwest to a quarry north of Line Lexington. No significant offsets of any of these members have been detected.

There is even clearer proof of the reality of the calculated thickness. Vertical sections measured in steep ravines or on hillsides agree in detail with sections of the same beds computed from dips and widths of outcrop along road or stream bed. At a number of places a contact or an individual bed has been traced diagonally down bluffs from upland level to river, road or creek bed, but no offset has been found. For much of the lower part of the section, south of Point Pleasant, it is possible when the leaves are off the trees to view the beds from the New Jersey shore. A number of thick strata can be seen sloping to the northwest down the river bluff, from the summit to the river road skirting its foot. Fault offsets are entirely lacking. The foregoing observations are believed to be sufficient basis for the positive assertion that fault repetition of strata in the Delaware River section of the Lockatong Lithofacies is negligible. It was necessary to state the case thus fully because it has been repeatedly suggested that the large thickness of the Newark Group is illusory. The field evidence in the Bucks County area is completely unfavorable to the hypothesis of extensive repetition of beds other than that already recognized as due to the major fault blocks which repeat whole lithofacies.

Exposures in the southern belt of Lockatong argillite are not as extensive as in the northern belt. A fairly good section occurs along Mill and Neshaminy Creeks from south of Rushland to near Wycombe.

A summary of the Mill Creek section is given in Table 20.

TABLE 20. *Stratigraphic Section of the Lockatong Lithofacies along Mill Creek*

	Feet
Tough, red shale and sandy argillite (at brook near Wycombe)	110
Gray shale and greenish-gray argillite	125
Tough, red shale	145
Gray shale and argillite	80
Tough, red shale	60
Gray shale	38
Red argillite (poorly exposed)	156
Gray, brown, and reddish-brown shale and argillite	267
Gray, medium-bedded argillite	64
Covered interval: gray shale near base, red near top	180
Tough, red shale	45
Thin- to thick-bedded, gray shale with thin, red interbeds	90
Alternating 20- to 50-foot members, dark-gray argillite and red shale and argillite	255
Gray and brownish argillite and black shale, with a few beds of limestone	61
Red and reddish-brown, thick-bedded argillite (in Millville quarry)	19
Dark-gray argillite with interbedded red members and a little very fine-grained, brownish sandstone	190
Reddish-brown argillite	40
Thick-bedded, dark-gray argillite, with sandy shale	175
Reddish-brown, thick-bedded, hard argillite (Neshaminy Cliffs member)	53

Massive- and thick-bedded, dark-gray argillite with interbedded, black and gray shale (Rushland quarry)	190
Medium-bedded, dark-gray argillite and gray shale	300
Interbedded, tough, gray argillite, brownish, sandy argillite, brown and gray shale	250
Interbedded, red, brown, and gray, very fine sandstone and shale	180
STOCKTON LITHOFACIES	
TOTAL	3,073

Within less than two miles west of Mill Creek, nearly the entire section above the beds in the Millville quarry grades along the strike into uniform red shale of Brunswick Lithofacies type.

The section of the southern belt of Lockatong Lithofacies at the Delaware River is only intermittently exposed. For that part of the area between the Delaware River and Stoopville, the section is summarized in Table 21.

TABLE 21. *Stratigraphic Section of Lockatong Lithofacies Between the Delaware River and Stoopville*

	Feet
Black shale	150
Red argillite and shale	280
Interbedded, brown, gray and red argillite	60
Red argillite and shale	160
Black and gray, tough argillite	750
Interbedded, red and gray argillite	20
Black and gray argillite	730
Total	2,150

The total thickness of 2,150 feet is, if anything, a little too large, yet it is much less than the thickness for the northern belt. Clearly, the Lockatong Lithofacies thins southward in much the same manner as it does westward in Montgomery County and northeastward in New Jersey.

West of Stoopville the main body of Lockatong argillite (the lower 1,500 feet) thickens rapidly. Not only does the width of outcrop increase, but the dips steepen. There is no reason to suspect important repetition due to faulting, though a minor contribution due to that cause cannot be denied. Inasmuch as measured strikes on outcrops near the northern and southern edges of the belt are parallel to the boundaries, the increase of thickness cannot be due in any large measure to gradation along the strike, though a fraction of the increase may be due to upper beds of Stockton sandstone passing laterally westward into Lockatong. It is believed that, in the main, the change of thickness is due to more rapid deposition of Lockatong sediments in a rather restricted area whose center was between Wrightstown and Penns Park. The upper half of this thick series grades rapidly westward into Brunswick red shale, and Mill Creek furnishes an excellent section of the interfingering red and gray beds.

Subdivisions

The section for the northern belt can be abridged as shown in the first column of figures in Table 22 (p. 88). The members tabulated have been traced along the strike to the Montgomery County line, as well as several miles to the northeast in New Jersey. In the second column of figures are thicknesses computed for a section along Pennsylvania

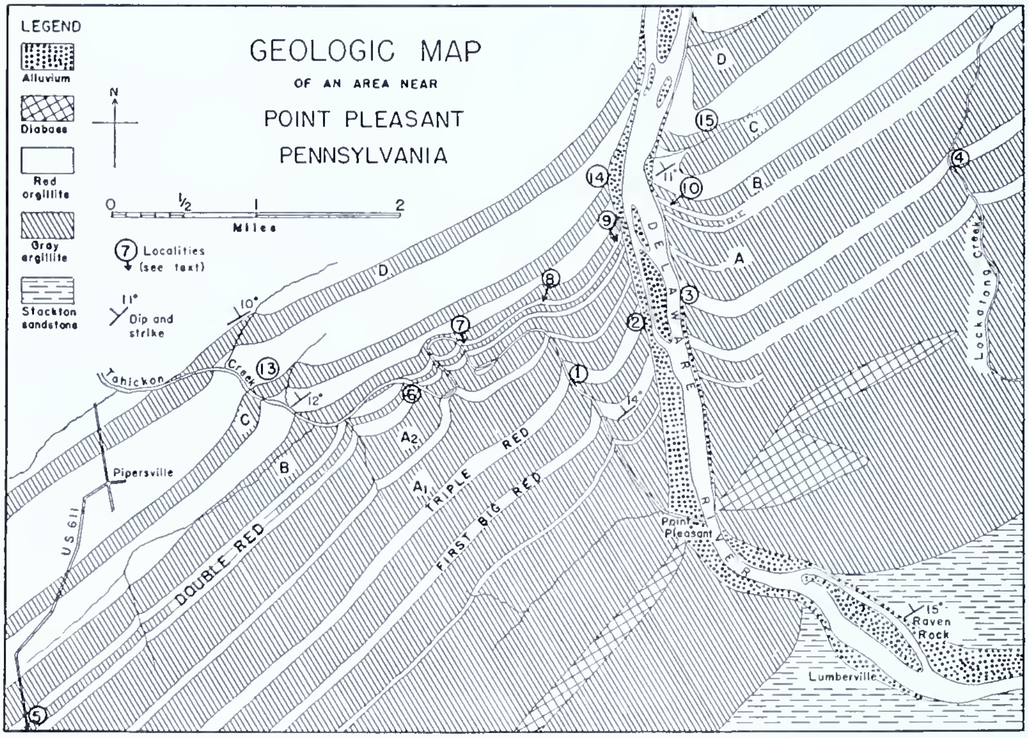
State Highway No. 313, and the third gives the section a mile east of the Bucks County line. The fourth and fifth columns show approximate thicknesses in the southern belt, near Delaware River and along Mill Creek, respectively. The correlation of members between the northern and southern belts, which is based on matching the sequence near the Bucks County line with that near Washington Crossing, is only tentative.

TABLE 22. *Stratigraphic Sections of Argillite of Lockatong Lithofacies*

	Tohickon Creek Feet	*Highway No. 313 Feet*	*County Line Feet*	*Wash'n Cros'g*	*Mill Creek*
Gray argillite "B"	246	270	60		
Double red member	105	190	350		
Gray argillite "A$_2$"	250	330	230	30	
Smith Corner red	30	110	280	560	
Gray argillite "A$_1$"	285	220	160		
Triple red member	138	250	200		
Gray argillite	250	410	230	150	
"First big red"	87	120	380	280	1270*
Gray argillite	250	210		60	
"First thin red"	22	90		160	
Gray argillite	2,205	680	570	730	830
Red argillite		10	40	20	53**
Gray argillite		1,290	1,790	750	920

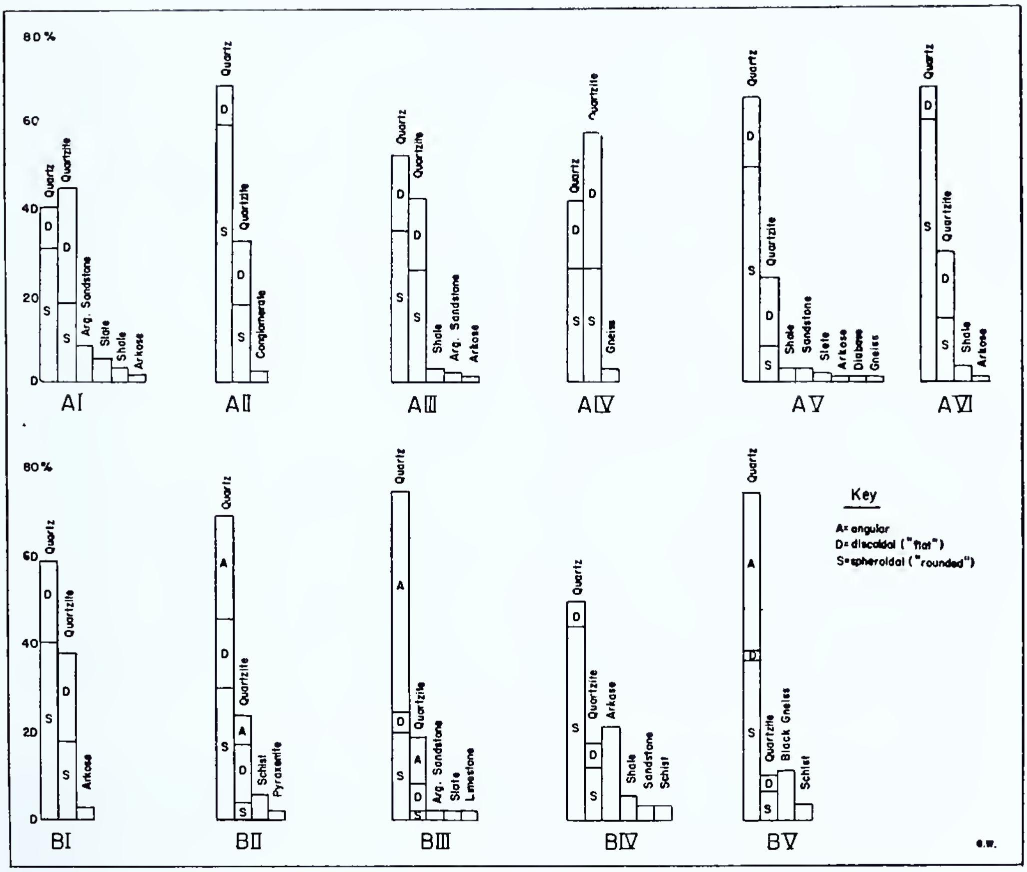
* Interbedded red and gray.
** Neshaminy Cliffs member.

FIGURE 9



Enlargement of part of Figure 8 of Point Pleasant area, to illustrate interbedding of red strata with gray argillite. Numbered localities 1 to 10 correspond to those in Table 23. Localities 13 to 15 correspond to columns 3 to 5 of Table 27.

Figure 10



Histogram of pebble counts of Stockton Lithofacies by L. F. Delwig. Location citied in text, p. 71.

The “triple red” and “double red” members are especially interesting as examples of continuity of strata only a few tens of feet in thickness. Figure 9 (p. 88) is a map of the area near Point Pleasant, where these and other members have been studied in detail (McLaughlin, 1944). In Table 23 are measurements of sections of these members given for the numbered localities on the map (Fig. 9, p. 88).

Table 23. *Stratigraphic Sections of the “Triple Red” Member, Lockatong Lithofacies*

Locality	*1* *Feet*	*2* *Feet*	*3* *Feet*	*4* *Feet*
Red argillite	24	20	25	15+ 9 covered
Black argillite	33	26	25	5+32 covered
Red argillite	42	51	50	10+20 covered
Black argillite	21	13	9	16
Red argillite	18	21	40	40

Stratigraphic Sections of the “Double Red” Member, Lockatong Lithofacies

Locality	*5* *Feet*	*6* *Feet*	*7* *Feet*	*8* *Feet*	*9* *Feet*	*10* *Feet*
Red argillite	40±	37	38	39	34	36
Gray argillite	20±	32	30	32	29	36
Red argillite	40±	33	21	30	22	27

Fossils

The Lockatong Lithofacies is the most fossiliferous division of the Newark rocks of the Delaware Valley, but in Bucks County it has not yet yielded many remains (Wherry, 1931, p. 163). Fish remains and crustaceans were reported by Wherry (1913): crustaceans, coelecanth fish, sharks, reptile bones, molluscs and plant remains by Bock (1945) and Bryant (1934); reptile teeth by Cope (1866) and Von Huene (1921); and crustaceans and coelecanth fish by Jepsen (1949) from exposures at Princeton, N. J.

Name and Correlation

One of the most astonishing features of the early literature is the lack of recognition of the Lockatong Lithofacies as a formation or lithologic unit. This probably resulted from the assumption that it owed its dark color to baking by diabase intrusions. The black argillite first received a name when Lyman (1895) designated the rocks as "Gwynedd" shale from the Gwynedd tunnel locality in Montgomery County. Because of Kümmel's (1898) work in New Jersey, however, the name Lockatong came to be adopted (Darton, 1909a; and Kümmel, 1909). It subsequently has been much used in Pennsylvania. The name is taken from Lockatong Creek which enters the Delaware River on the New Jersey side east of Lumberville. Excellent exposures of the Lockatong argillite occur in Lockatong Creek Valley.

The Lockatong Lithofacies in Pennsylvania is stratigraphically continuous with the rocks of the type locality in New Jersey. No thick, lithologic equivalent of the Lockatong is recognized in other adjacent Newark areas, nor in distant parts of the New York to Virginia Triassic sections. The fossiliferous black shales in Connecticut Valley are near the top of the section and are late Brunswick in age, if the lavas of Connecticut and New Jersey are contemporaneous. The coal beds of the Richmond, Virginia, basin are near the base of the series in the arkose, and any correlation with the Lockatong would be dubious. Indeed, if any beds in the Richmond basin are to be correlated with the Lockatong Lithofacies, the black fissile shales at the base of the Vinita Sandstone (Shaler and Woodworth, 1899, p. 423) are the most likely, since they contain *Pseudoestheria* similar to that of the Lockatong. In the Deep River coal basin of North Carolina (Campbell & Kimball, 1923), the coal occurs in a middle formation, the Cumnock, with a red shale and sandstone above it. The Cumnock contains *Pseudoestheria* and other fossils similar to those of Lockatong Lithofacies. Shales near the center of the Durham basin likewise contain *Pseudoestheria* and ostracods according to W. F. Prouty (1931, p. 480).

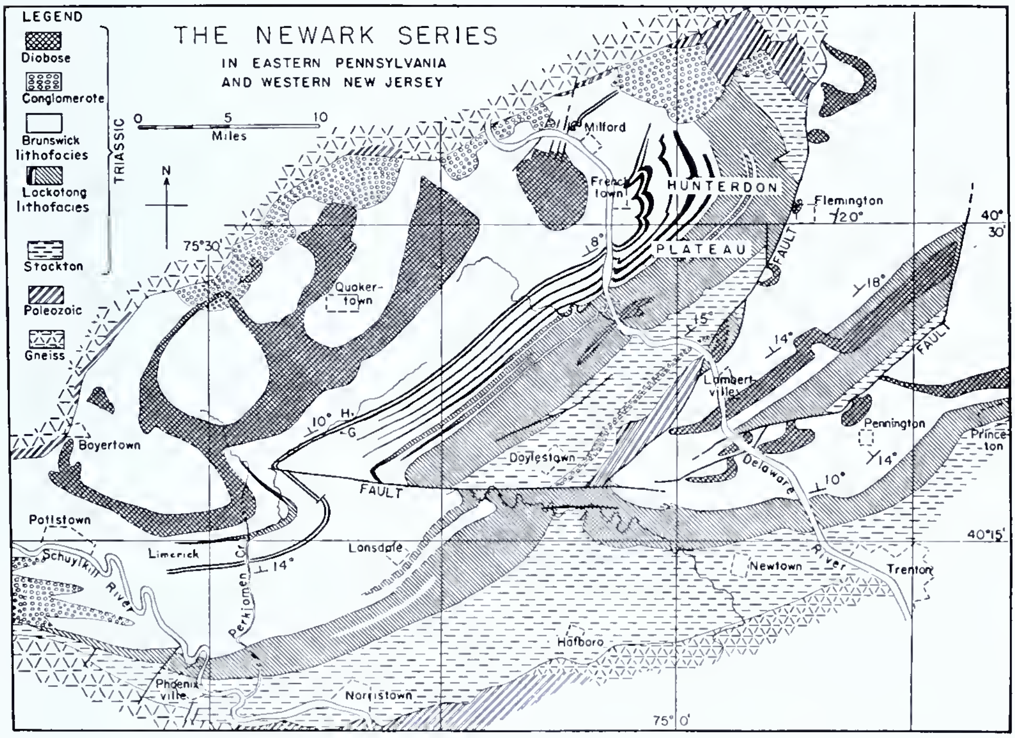
In the past, the Lockatong Lithofacies has often been considered a possible time equivalent of the Lettenkohle at the base of the Keuper (Table 29, p. 107), Wherry, 1912c, Bock, 1946). Bock (1952) has suggested a correlation with the Schilfsandstein and Bunte Mergel beds of the middle Keuper (Upper Triassic).

Stratigraphic Relations

The Lockatong Lithofacies overlies the Stockton conformably. Local interfingering near the contact is not sufficient to cause the lower boundary in the northern belt to deviate appreciably from a straight strike line. In the southern belt, the section south of Rushland shows interbedding of shales and sandstone of Lockatong and Stockton Lithofacies, respectively, and it is suspected that the base of the Lockatong trends slightly downward to the west.

Gray argillite at the top of the Lockatong section interfingers extensively with Brunswick red argillite and shale. The percentage of red shale increases upward in the stratigraphic column until it is finally dominant. In the section between Rushland and Wycombe, interbedding is extensively developed and the Lockatong Lithofacies grades rapidly westward along the strike into red shale of Brunswick type. In any single section, the main body of Lockatong is overlain in part by Brunswick, with a thick series of interbedded red and gray shales marking the transition. The Lockatong Lithofacies thins steadily westward through Montgomery County. Successive beds at the top of the main body grade into red shale or sandstone, until the remnant, only a few hundred feet thick several miles west of Phoenixville, disappears a few miles beyond. The relations just described are shown in Figure 11 (p. 91).

FIGURE 11



Sketch map of east-central Pennsylvania and west-central New Jersey to illustrate distribution of Lockatong Lithofacies and its relations to other stratigraphic units.

Brunswick Lithofacies

Distribution

If the diabase bodies that intersect it are disregarded, the Brunswick Lithofacies may be said to occur in Bucks County in two large areas and one small one. The southeastern of the two large areas is roughly triangular. Its northern tip is at the Delaware River two miles north of New Hope; its southeastern corner at the river south of Washington Crossing; its western corner is at Furlong. The area is completely divided from east to west by the trap intrusion at Solebury Mountain south of New Hope. Northeastward in New Jersey this area splits into two wide belts separated by a band of Lockatong and Stockton Lithofacies that is brought up by the Hopewell fault.

The second large area occupies a major portion of the northern and northwestern part of Bucks County. Its southern edge crosses the Delaware River about two miles north of Point Pleasant and trends southwestward to the Montgomery County line about two miles southeast of Telford. Except for the diabase areas and associated hornfels, the Brunswick sandstone and shale extend to the narrow intermittent strip of fanglomerate at Monroe, Bursonville, Passer and Spinnerstown. Within the Brunswick outcrop area, diabase covers an elliptical region five miles in diameter between Ferndale and the Delaware River. The Haycock sheet and other associated diabase bodies subdivide the northwestern portion of the area of sedimentary rocks into four main parts and three smaller areas. The largest of these is roughly elliptical, eight miles long from northeast to southwest and four miles wide, with Quakertown at its center. Another nearly equal area lies north of it with Pleasant Valley nearly central. A third, north and west of Milford Square, under much of which the rocks are altered to hornfels, measures three by six miles. The fourth, around Geryville at the westernmost corner of Bucks County, is the edge of a much larger area in Montgomery County. The three small areas are in the vicinity of Applesbachville, Rich Hill, and Quakertown airport.

At the western edge of Bucks County southeast of Line Lexington, a patch of a few square miles is underlain by red shale with a thick interbed of gray shale of Lockatong Lithofacies. This is also part of a large area in Montgomery County. Thin and thick bands of red shale and argillite interfinger with the upper part of the Lockatong Lithofacies.

Topographic expression

The Brunswick shale is much more easily eroded than the underlying Lockatong argillite or the intruding diabase. It, therefore, forms a lower, gently rolling terrane with broad shallow valleys and low ridges parallel to the strike of the beds. The more resistant, interbedded, dark shales of Lockatong Lithofacies in the lower Brunswick form a few more or less definite ridges. The most conspicuous of these is made by the combined effects of the upper and lower Graters members south of the Northeast Branch of Perkiomen Creek in the western part of Bucks County. A few of the larger stream valleys are fairly deep and steep-sided but even these slopes are decidedly more gentle than those of similar streams that cut Lockatong argillite. Tohickon Creek is a good example; its course across Brunswick shales is in a broad, open valley with gentle slopes, but where it crosses Lockatong argillite it flows through a steep-sided gorge rimmed by high cliffs. The Delaware River bluffs are rather steep whether cut in Lockatong or Brunswick, but an appreciable difference may be noted. The cliffs cut in Brunswick shales from Erwinna to Kintnersville are an exception. Through a part of this extent they are probably protected by a thin, but relatively resistant, capping stratum of gray shale, and for the remainder of the distance, they are capped by baked hornfels beneath the Coffman Hill diabase sheet.

Lithology

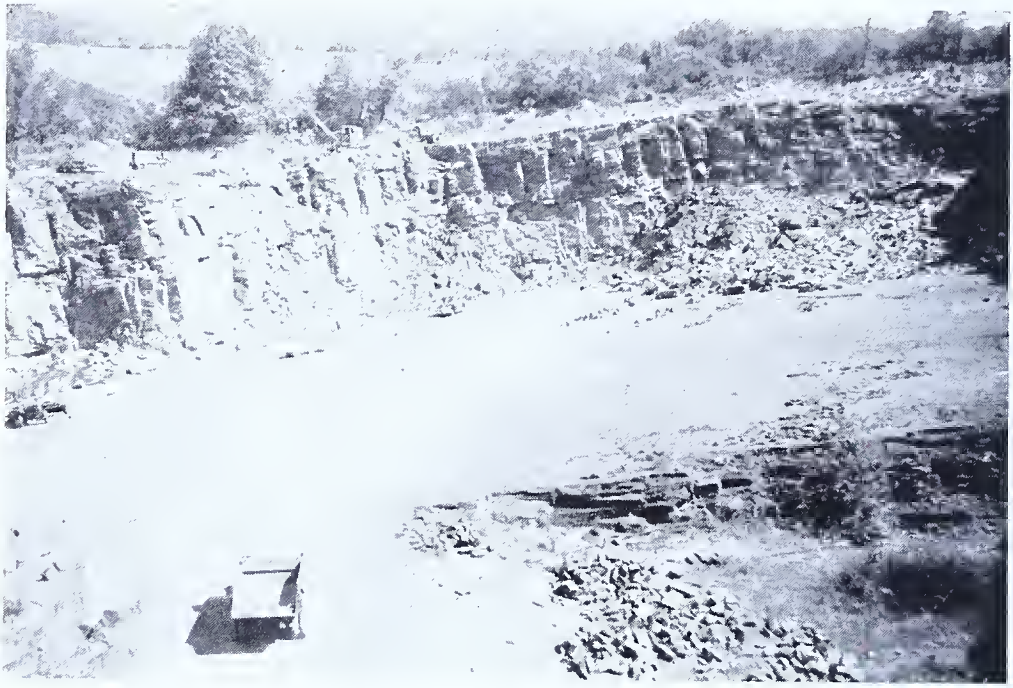
The Brunswick Lithofacies, except for those parts of it near the north border, is lithologically the most uniform of the three major sedimentary units of the Newark Group in Bucks County. In the greater part of the Delaware River section the rock is a weak, bright-red, argillaceous shale that readily crumbles into thin flakes or ragged fragments. There is no visible grain, even when examined with a hand lens, and the typical shale is not micaceous. The bedding is wavy and irregular; fissile shale is extremely rare. Ripple marks are found at many places, and mud cracks are common. Photographs of Brunswick exposures are reproduced in Plates 14 and 22-B.

In the lower part of the section a considerable amount of the rock is a rather thick-bedded, tough, red argillite, similar to that already described as interbedded with the Lockatong gray argillite. The transition from red argillite to the typical, thin-bedded, weak red shale is quite gradual and involves a great thickness of beds. A few thicker beds of more resistant argillite appear high up in the section, but most of the rock is a monotonous succession of weak, fragile shale.

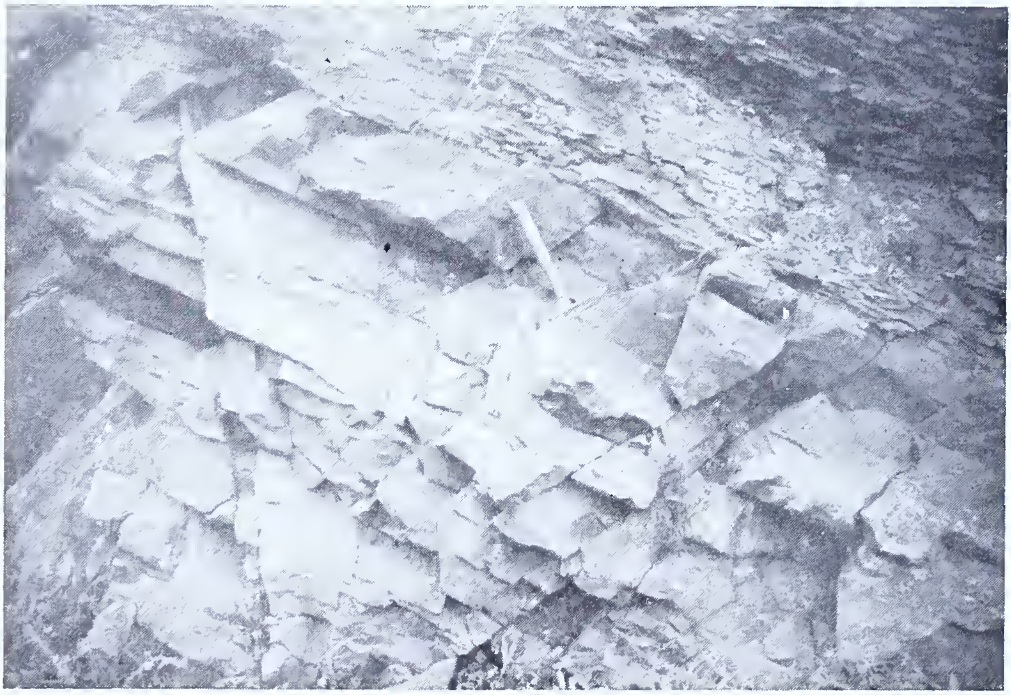
In the lower part of the Brunswick section several dark gray argillite members are interbedded with the red. These beds are lithologically indistinguishable from Lockatong Lithofacies. Higher in the section, a few gray shale beds occur, but in general they are weaker and more thin-bedded than typical Lockatong. Exceptions are the pair of hard, gray argillite members designated the Graters (McLaughlin, 1933, p. 427) and the thick gray argillite member, the Perkasie, which forms the prominent ridge north of the town of that name. The thinner gray shale members are either weak, dark-greenish-gray or light-bluish-gray, thin-bedded shale. Contacts of red and gray shale show the same type of transition as already described in connection with the Lockatong Lithofacies, with local gray-in-red breccia or mud-cracked gray with red crack filling; never the reverse.

Near the north border a number of beds of very fine-grained, micaceous, red sandstone are interbedded with the weaker red shale. The amount of this sandstone increases towards the border. Lithologically, these beds closely resemble the red sandstones of the Stockton Lithofacies. Unlike the Stockton, however, they contain little arkose. In a few places some of the sandstone beds exhibit a sprinkling of small, rounded quartz pebbles. The normal red shale is never cross-bedded,

PLATE 14



A. Quarry in gray shale member G, one and one-half miles southwest of Sellersville. Floor of quarry in red argillite of Brunswick Lithofacies.



B. Limestone conglomerate interbedded with Brunswick red shale and sandstone, one hundred yards south of Monroe.

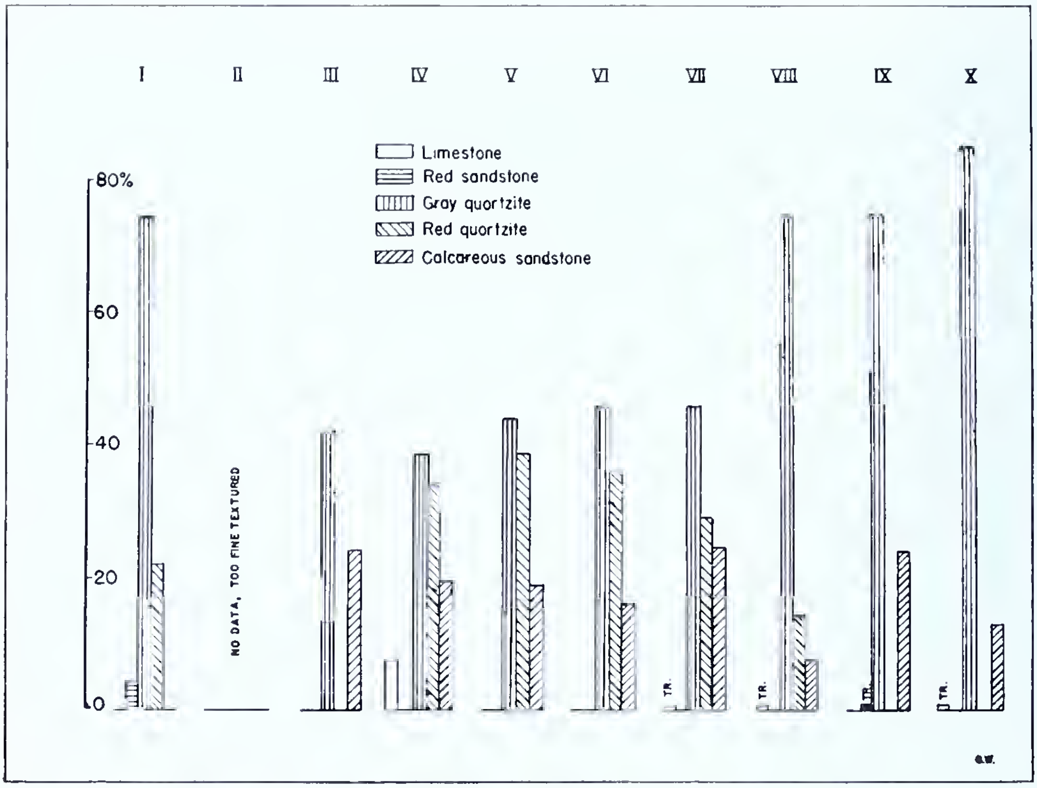
but lenticular structure and cross-bedding are not uncommon in Brunswick sandstones near the border. On a large scale, however, fairly uniform bedding is the rule. Still another border facies is a fine-grained sandstone or shale that contains closely packed, tiny flakes of greenish, brown and gray shale, probably derived from the Martinsburg Formation. Some strata near the large bodies of fanglomerate contain small flakes of limestone.

The fanglomerate is the most distinctive border facies that interfingers with the red shale and sandstone. The relations are visible along the river road (U. S. Route No. 611) south of Monroe, where the beds dip so gently that the change along the bedding is readily followed. The transition from red shale and sandstone to fanglomerate is gradual. As a sandstone bed is traced towards the border, at first a few scattered pebbles appear in it. Farther north the pebbles are larger and more numerous; the bed thickens, and additional bands of conglomerate appear. At Monroe a large exposure (Plate 14, B) shows interbedded red sandstones, shales, and limestone conglomerate of the "Potomac marble" type which comprises about half the total exposed thickness. The conglomerate is in beds several feet thick and consists of closely packed, angular limestone phenoclasts in a brownish, fine-grained, sandy to argillaceous matrix. A part of the same body of limestone fanglomerate is exposed directly across the Delaware River from Monroe at Holland Church, New Jersey. There the rock is practically a limestone breccia of fragments ranging up to several inches in diameter in a calcareous matrix. At that place several cobbles of Pre-Cambrian gneiss occur in the conglomerate.

A small lens of cobbly, quartz conglomerate interrupts the red shales and sandstones 300 yards west of the road that climbs the bluff at Narrowsville. This is in all probability the attenuated edge of a bed that forms a part of a thick body of fanglomerate in the "Pebble Bluffs" in New Jersey, east of Narrowsville. The exposures along the Delaware River road in New Jersey are excellent. Interbedded conglomerate and red sandstone occur with an apparent thickness of 1,500 feet of strata that dip about 15° NW. As several faults are exposed, the true thickness may be less than 1,000 feet. The conglomerate beds are thickest, most numerous, and contain the largest cobbles somewhat above the middle of the section. These beds form rapids in the Delaware River and are visible as large ledges at low water. A few of these extend practically to the Pennsylvania shore. According to counts made by Palmer (1948), the largest percentage of the pebbles is of fairly well-rounded quartzite, but a considerable number are of limestone or calcareous sandstone (Fig. 12, p. 96). In the coarsest conglomerate, boulders nearly a foot in diameter are common, and a few are nearly two feet long.

At most places along the north border the fanglomerate is deeply weathered and does not appear in outcrop. The quartzite facies disintegrates to sandy soil, thickly strewn with the broken, rounded cobbles. The limestone facies weathers by solution of the limestone pebbles, leaving the more siliceous matrix as yellowish, weathered blocks of "honeycomb rock." Discontinuous exposures of limestone breccia

FIGURE 12



Histogram of pebble counts of fanglomerates at Pebble Bluffs, N. J., by J. T. Palmer.

or "Potomac marble" crop out in a small brook three-fourths of a mile west of Franklin School in northern Bucks County. They are associated with red shale that contains a bed six feet thick of light, bluish-gray limestone of uniform texture, probably composed of a mud derived from the neighboring Paleozoic limestone.

Petrographic analyses

Ryan (1948) carried out petrographic analyses of specimens of Brunswick red shale from two localities. These are given below:

TABLE 24. *Petrographic Analyses of Red Shale of Brunswick Lithofacies*

Constituent	*Locality B1*	*Locality B2*
Groundmass (see Remarks)	68.8%	75.0%
Calcite	5.3	3.0
Feldspars	1.2	1.0
Quartz	24.7	20.0
Opal	...	1.0

Locality B1. One and one-half miles east of Kintnersville.
Locality B2. Kintnersville.

Remarks: Groundmass composed of limonite, hematite, and unidentified clay minerals.

Fragments of detrital quartz and feldspar are very small and subangular; quartz fragments, transparent and stained with hematite; calcite and opal secondary.

In the description of the Stockton Lithofacies, reference was made to petrographic studies by Gerhard (1952). His specimens did not include

Brunswick shales or sandstones from Bucks County. However, his general results for the Gettysburg (Brunswick) sandstones of Lebanon County are of interest here. He found these highly quartzose, slightly feldspathic in a few places, and containing numerous rock fragments. Heavy mineral analyses showed a high content of rounded tourmaline, zircon and rutile, constituting a reworked sedimentary mineral suite. The salic igneous suite was also abundant. These results point to a provenance north of the Triassic belt, as opposed to the southern provenance indicated for the Stockton Lithofacies.

An analysis of a specimen of Brunswick limestone fanglomerate from Monroe by Ryan, is as follows:

Pebbles of limestone and some detrital quartz		49.7%
Matrix		36.1
consisting of:		
Quartz	10.3%	
Calcite	13.6	
Feldspars	12.2	
Cement of limonite, hematite, and unidentified clay minerals		14.2

Willard (1956) noted lithologic similarities between quartzite cobbles at Pebble Bluffs and the Green Pond (Silurian) quartzite of northern New Jersey. He also identified Silurian fossils in some of the limestone pebbles.

Metamorphism

Near the intrusive diabase sheets and dikes, Brunswick shale has been altered to a dark, tough hornfels that closely resembles Lockatong argillite. The change of color is due to reduction of the red ferric oxide to ferrous oxide. The width of outcrop of the altered zone ranges from only 100 yards along the north foot of Bowman Hill to more than one-half mile beneath the Haycock sheet. The latter corresponds to a thickness of at least 350 feet of strata; the former cannot be expressed as a thickness, since the intrusion is a dike that cuts perpendicular to the bedding. The transition from normal red shale to true hornfels is gradual. The first effect is a change to purplish red. With increased baking, the purple tone becomes darker, and the rock grades to dark gray or blue-black. This is accompanied by increased toughness and apparent thickening of the bedding. Nodules of secondary minerals appear, or the rock may have a ribbon-banded appearance due to variable development of secondary minerals in layers. Close to the contact with the intrusive, at many places, the color is a lighter gray than that of less altered rock. Weathered fragments are light bluish-gray, and the soil derived from the metamorphosed shale is a light, ashen gray. In a considerable area south of Steinsburg the altered beds are greenish and pinkish-gray and weather almost white.

The petrology of the metamorphosed shale is described by Ryan (Chapter IV, p. 154).

Southeast of the Haycock diabase sheet and northeast of its northern end, the wide band of undoubted hornfels merges with an underlying series of 300 to 400 feet of gray to purplish rock whose precise character is uncertain. On the basis of its color, the author originally mapped it as hornfels. However, Watson (personal communication) found no development of secondary minerals in microscopic sections. If the abnormal color is interpreted as due to baking, it is necessary to postulate that the change was strictly confined to reduction of the ferric oxide pigment to ferrous oxide.

The character of this ambiguous rock varies along the strike. Thus, along the former Liberty Bell electric railway northwest of Perkasie, much of the rock is dull pinkish to purplish gray, rather tough, and of a silty texture. With it occurs some greenish gray siltstone and practically normal red shale. At the same horizon in the north cut of the Perkasie tunnel, there is less pinkish and reddish rock, and more gray shale that does not appear metamorphosed at all. This would never have been considered as altered, had it not been part of an almost continuous exposure whose upper beds were massive, tough, dark gray argillite very similar to the true hornfels. A few miles farther northeast, along Pennsylvania State Highway 313, the rock is mostly tough, dark-gray to purplish gray argillite and shale, much of which has the ashen appearance on weathered surfaces that is associated with baked Brunswick shale.

The belt probably contains a considerable amount of originally gray or greenish siltstone and shale, interbedded with formerly red shale which may have been very slightly altered by contact action. Since the alteration, if any, has been slight, the belt is shown on the geologic map of Bucks County (Plate 2, in pocket) as shale of Brunswick Lithofacies, but is enclosed within an overprinted boundary that indicates the outer limit of discoloration.

Immediately beneath the ambiguous rocks just described, unaltered red shale occurs in a zone whose width ranges from 200 yards to about one-half mile. Stratigraphically below this is another band of dark-gray shale that has been variously regarded as hornfels or as gray argillite similar to Lockatong Lithofacies. It forms a prominent ridge from Ottsville to Sellersville, and is designated the Perkasie member. The fact that it is continuous along the strike with the hornfels beneath the Coffman Hill diabase sheet was the main reason for interpreting it at first as baked shale. A consideration of all the evidence, including sections in Montgomery County and in New Jersey, points to the conclusion that this outer band is naturally dark-gray argillite, but that it may have been subjected to slight baking.

North of Milford, New Jersey, at practically the same stratigraphic level, a pair of gray argillite members, each 50 feet thick are separated by an equal thickness of red shale, an aggregate of 150 feet. The Perkasie member at Tohickon Creek is 144 feet thick and has 10 feet of red shale 40 feet above its base. It is suggested that most of the central red shale may have been baked just sufficiently to change its color. Possibly the alteration was aided by the presence of an excess of ferrous oxide in the enclosing gray argillite. A very similar, thick, gray argillite member with some red argillite near its center occurs at practically the same stratigraphic horizon at Lederachsville and at Schwenksville in Montgomery County. In all probability, the Perkasie, Milford, and Lederachsville members are one and the same.

Columnar sections and Thickness

There are three good sections of large parts of the Brunswick Lithofacies in its northern area. One is along the Delaware River from the top of the Lockatong section north of Point Pleasant to the mouth of Tinicum Creek, and thence inland to the base of the Coffman Hill trap sheet. The second section is along the southward-flowing part of Tinicum Creek east of Ottsville, with extensions northwest and southeast along tributary brooks. The third section is along Tohickon Creek east and north of Pipersville and then, after a considerable interruption, from southwest of Ottsville to the vicinity of Haycock Mountain. Individual gray shale members have been traced along the strike between the sections and are definitely correlated. These members, C to M inclusive, are shown in Figure 8 (p. 84). The stratigraphic sections of red beds of the Brunswick Lithofacies are given in Table 25 (p. 100).

The tracing of individual gray shale members for a number of miles and the agreement of horizontal and vertical sections indicate that there can be no large percentage of repetition of strata due to faulting. The arguments that show the reality of the large thickness are the same as given in detail for the Lockatong argillite.

In 1891, a well drilled at Revere to 2,084 feet (Lesley, 1891) penetrated interbedded red and gray shales and sandstones that can be correlated satisfactorily with the exposed shale members to the south (McLaughlin, 1943). That the Brunswick Lithofacies is at least 2,000 feet thick below Revere is shown by the fact that the rock at the bottom of the well was still dominantly red and brown shale and sandstone. According to the correlation, the drill stopped about 750 feet above the top of the Lockatong-Brunswick transition beds.

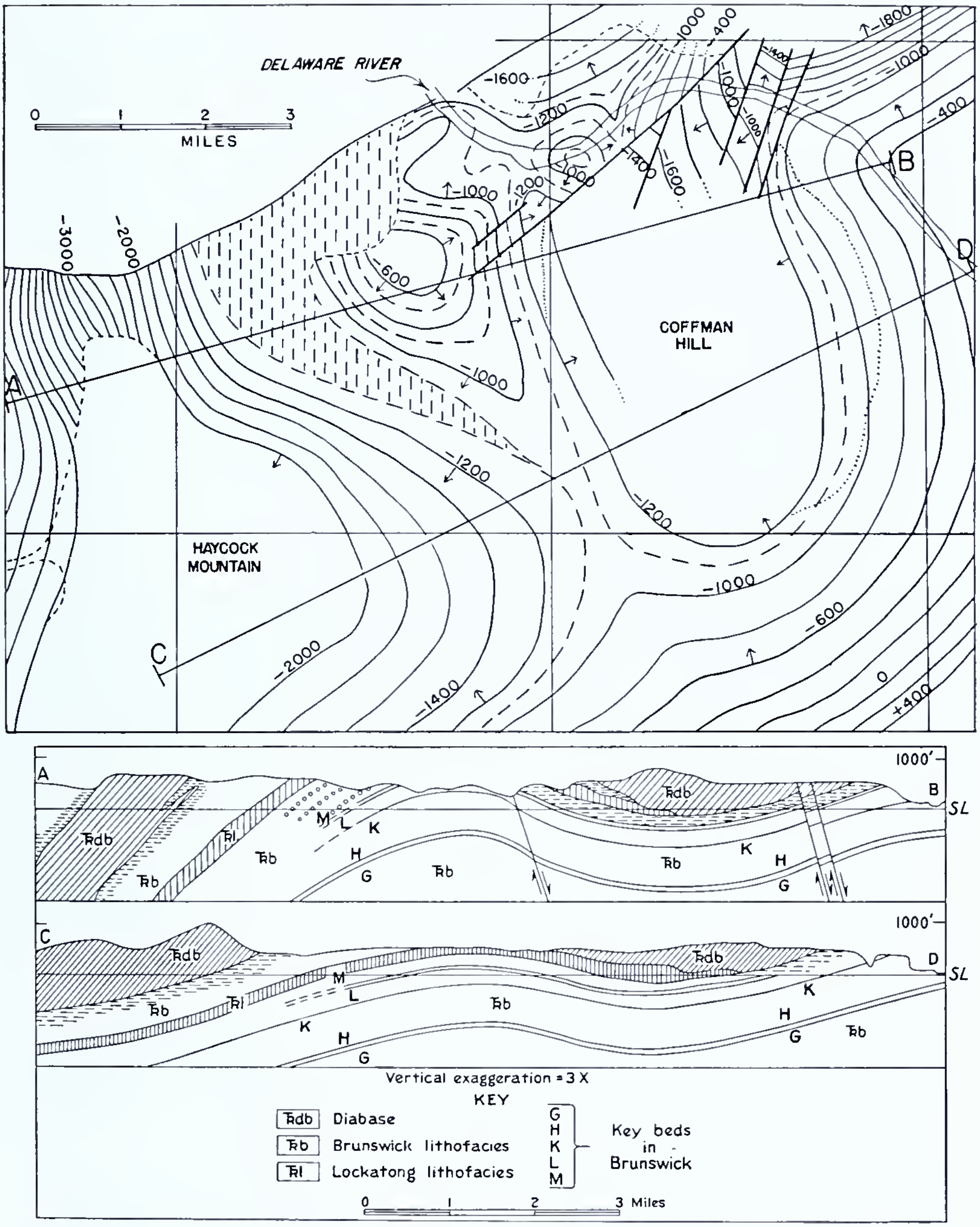
In "Structure of the Triassic Rocks" (Chapter IV, p. 126), it is shown that the uppermost beds southeast of Haycock Mountain are about 800 feet higher in the series than those that underlie the southwestern edge of the Coffman Hill diabase sheet. Also, the shales and fanglomerates near the north border at and southwest of Monroe for about five miles are all lower than the base of the Haycock sheet (Fig. 13, p. 101). Northwest of the Haycock sheet is the Quakertown synclinal basin, in which a thick series of red shale is exposed, and in part metamorphosed. At the northwest and north, the red shale passes into quartz fanglomerate that is apparently, in part, the youngest Triassic sediment in Bucks County. Dips and widths of outcrop in several sections on the limbs of the syncline give roughly accordant values of the thickness as approximately 5,000 feet, all of which, if the intrusion is a sill, must be stratigraphically higher than the beds southeast of the diabase. The total apparent thickness of the Brunswick shale in Bucks County therefore is only slightly less than 9,000 feet. However, if as

TABLE 25. *Stratigraphic Sections of Red Beds of Brunswick Lithofacies*

	Tohickon Creek Feet	*Tinicum Creek Feet*	*The Delaware River Feet*
Diabase (Haycock sheet)			
Thick-bedded, tough, dark-gray hornfels	350		
Thick-bedded, gray, purplish, and reddish argillite, perhaps in part metamorphosed, with some red shale and greenish siltstone	300		
Thin-bedded, red shale	180	Diabase	
Thick-bedded, tough, greenish-gray argillite, perhaps slightly metamorphosed	94	200	
Red shale	10		
Thick-bedded, dark-gray argillite	40		
Thin- to thick-bedded, red shale	250	215	
Thin-bedded, weak, blue and gray shale (M)	11	10	
Thin-bedded, red shale	17	50	
Thin-bedded, weak, blue and gray shale (L)	4	15	
Thin-bedded, red shale	>140	300	310
Thin- and medium-bedded, grayish and greenish shale (K)	cov.	15	10
Red, weak shale		450	360
Thin-bedded, gray and greenish shale (I)		5	12
Thin- and medium-bedded, red shale		400	309
Thin- to thick-bedded, gray shale (H) Upper Graters		45	44
Thin- to thick-bedded, red shale		45	48
Thin- to thick-bedded, gray shale (G) Lower Graters	42	51	52
Thin- and medium-bedded, red shale	220	200	190
Thin-bedded, greenish-gray shale (F_2)	11	6	10
Thin-bedded, red shale	11	cov.	9
Thin-bedded, greenish-gray shale (F_1)	6		8
Thin- and medium-bedded, red shale	85	100	83
Thin- and medium-bedded, gray and greenish shale (E)	22	80	67
Thin- to medium-bedded, red shale	350		175
Thin- to thick-bedded, gray shale, and argillite (D_2)	absent		25
Medium-bedded, red shale			27
Thin- to thick-bedded, gray shale and argillite (D_1)	50		100
Medium-bedded, red shale	306		400
Medium- to thick-bedded, gray shale and argillite (C_2)	33		30
Thin- to medium-bedded, red shale	31		25
Medium- to thick-bedded, gray shale and argillite (C_1)	70		50
Medium-bedded, tough, red shale	192		201
Chocolate-brown transition beds to argillite of Lockatong Lithofacies.			
	2,825	2,187	2,545

is quite probable, the floor of the basin shelves northward, the beds may also be attenuated in that direction. If this is the case, a total thickness of 9,000 feet of red shale would not be encountered in a well drilled at any one place. Nevertheless, the thickness of the Brunswick Lithofacies is great, and it may well reach a true vertical thickness of as much as 6,000 feet at some places.

FIGURE 13



Structure contour map and geologic cross sections in vicinity of Coffman Hill to show structures and their probable relation to the intrusives.

Exposures in the southern area of Brunswick shale are numerous but scattered, and there is no single, good section through a large thickness of strata. Dips and widths of outcrop indicate at least 6,000 and possibly 7,000 feet of red shale with thin, interbedded, gray members. This measurement is made from the top of the Lockatong section of the southern belt drawn on the gray argillite member, 150 feet thick. If the correlation of sections (Table 22, p. 88) is correct, this is much lower than the assigned top of the Lockatong section in the northern belt. The greatest source of uncertainty in the southern belt is the scarcity of exposures between Jericho Mountain and the Buckmanville fault. The shales near Buckmanville and south of the fault are the youngest Newark beds in the southern belt within the limits of Bucks County. Northeastward in New Jersey the throw of the Buckmanville (Hopewell) fault increases, so that Lockatong argillite comes to the surface north of it. This makes it possible to establish the stratigraphic position of the Brunswick shale north of New Hope, inasmuch as the latter is on the strike of red shales in New Jersey that overlie Lockatong argillite. The highest beds of Brunswick shale north of New Hope are about 3,500 feet above the top of the Lockatong Lithofacies.

The preceding discussion has a bearing on the question of occurrence of lava flows in Bucks County. The nearest exposure of a surface flow is at Sand Brook, New Jersey, about five miles northeast of Center Bridge, Pennsylvania. It lies in a syncline of Brunswick red beds at least 8,000 feet above the top of the Lockatong Lithofacies. The only place in Bucks County where beds equally high in the series occur is near the axis of the Quakertown syncline southwest and west of Steinsburg. The diabase at the Lehigh County line west of Steinsburg is an irregular intrusive. Lava flows may have existed in the Bucks County area, but if so, have been eroded completely.

Subdivisions

The stratigraphic sections in Table 25 (p. 100) are combined into a single section in abridged form (East, Northern belt) in the first column of figures in Table 26 (p. 103). The second column gives thicknesses in a stratigraphic section (West, Northern belt) through Perkasie and Silverdale. Correlation of members in the southern belt with those in the northern belt is not conclusive. The most consistent identifications are obtained from the assumption that the conspicuous gray shale beds that pass through Woodhill are the southern equivalents of members G and H (the Graters) of the northern belt. The tabulation of thicknesses for the southern area in the last column follows this interpretation. The uppermost beds of the northern Lockatong section are included to show the relationships in a thicker stratigraphic column (Table 26, p. 103).

TABLE 26. *Correlation of Stratigraphic Sections of Brunswick Lithofacies*

	Northern Belt		*Southern Belt*	
	East *Feet*	*West* *Feet*	*Feet*	
Diabase (Haycock)	...	...	....	Diabase (Jericho)
Dark-gray hornfels	350	425	150 :	hornfels
Interbedded, gray, purplish and reddish argillite and shale	300	400		
Red shale	180	140	1700	Red shale
Gray argillite (Perkasie Member)	200	380		
Red shale with gray members L and M	590	610		
Gray shale "K"	15	17		
Red shale with gray member "I"	770	700		
Upper Graters gray shale "H"	45	50	120	Red shale with conspicuous gray shale beds (Woodhill members).
Red shale	46	70		
Lower Graters gray shale "G"	52	50		
Red shale with gray member "F"	316	280	480	Red shale
Gray shale "E"	60	40		
Red shale	300±	370		
Gray shale "D"	100±	50	30±	Gray shale
Red shale	350±	500	1000±	Red shale with a few thin, gray beds
Gray shale "C"	120	50		
Red shale	200	300		
Gray shale "B"	246	60		
Red shale	105	350		
Gray shale "A_2"	250	230	30±	Gray shale

With a few exceptions the gray shale members become gradually thinner southwestward along the strike. Member C contains a thick body of red shale, and the resulting duplication of the gray shale can be recognized at many places some miles apart. Table 27 (p. 103) compares six sections of member C over a distance of 18 miles.

TABLE 27. *Stratigraphic Sections of Gray Shale Member C*

				Delaware River		
	Blooming Glen *Feet*	*Dublin* *Feet*	*Tohickon Creek** *Feet*	*West Bank†* *Feet*	*East Bank‡* *Feet*	*Oak Grove N. J.* *Feet*
Gray shale C_2	10	10	33	30	25	23
Red shale	30	40	31	25	38	23
Gray shale C_1	45	50	70	50	70	37

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* Locality 13 in map, Fig. 9 (p. 88).
† Locality 14, Fig. 9.
‡ Locality 15, Fig. 9.

Member D at the Delaware River consists of two gray parts separated by red shale, but between the Delaware River and Tohickon Creek the upper portion disappears. The lower gray part thins from 100 to 50 feet, but then retains nearly this thickness southwestward to Silverdale, beyond which it thins considerably to the Montgomery County line.

Member E appears to range irregularly in thickness and was located with difficulty locally. Toward the southwest it thins and grades into red shale. The last exposure in that direction is in the Reading Railroad cut south of Derstines, where the section, in descending order is:

Blue-gray shale	10 feet
Red shale	15 feet
Gray and brown shale	12 feet

The gray-green shale member F is best exposed at the Delaware River. It persists for several miles northeastward in New Jersey. Southwestward, it disappears a few miles beyond Tohickon Creek.

The prominent gray argillite and shale members G and H have been called the "Graters shales" from Graters Ford on Perkiomen Creek in Montgomery County (McLaughlin, 1933). They have been traced a longer distance than any other members (McLaughlin, 1948) from hills northeast of Frenchtown, New Jersey, to Limerick in Montgomery County (Fig. 11, p. 91). West of there they are apparently cut off by a fault. Table 28 compares stratigraphic sections of these members throughout most of their extent.

TABLE 28. *Stratigraphic Sections of the Graters Shales (Members G and H)*

	Gratersford Feet	*Morwood, Montg. Co. Feet*	*Derstines Feet*	*Tinicum Creek Feet*	*Delaware River Feet*	*Frenchtown, N. J. Feet*
Gray shale H^1	41	50	covered	3	1	. .
Red shale	77	37	covered	80	68	. .
Gray shale H	28	30	covered	45	44	42
Red shale	40	30	10	48	48	55
Gray shale G	40	60	40	51	52	56

The greenish-gray shale member K is a remarkable example of continuity of a thin stratum for a number of miles. It has been found wherever exposures are adequate, from the Delaware River north of Lodi to the Reading Railroad cut at Sellersville. North of Lodi it is only three feet thick but increases to 10 feet within a mile to the south and remains between 10 and 17 feet thick from there to Sellersville, an air line distance of 18 miles. At several localities from north of Lodi to Tinicum Creek east of Ottsville (a distance of 8 miles), there is a bed of weak, blue shale one foot thick, 10 to 20 feet below K and separated from it by red shale. Such remarkably uniform sedimentation suggests the existence of a lake.

The thin, gray shale members L and M are of nearly uniform thickness throughout the area bounded by Kintnersville, Ferndale and Trauger School, as well as along Rapp Creek north of Ottsville. Along the east side of the Coffman Hill area they merge with the hornfels beneath the diabase sheet and are indistinguishable. On the road up the hill west of Erwinna about 15 feet of gray shale is overlain by 46 feet of red shale, and this in turn by hornfels. The gray stratum, 15 feet thick, is believed to be member L, whereas member M is lost in the metamorphosed shale immediately above. An identical sequence occurs in a ravine one-half mile southwest of the locality.

The thick, Perkasie, gray argillite member that crosses Tohickon Creek west of Ottsville and continues southwestward past Perkasie and Sellersville has been discussed above (p. 98).

Fossils

The Brunswick Lithofacies in Bucks County has yielded very few fossils (Wherry, Chapter IV, p. 114). No actual remains of animals have been reported, but footprints were found by Ryan and Willard (1947) and fossil plants were found by Wherry (1916a).

Name and Correlation

The Brunswick Lithofacies as a unit was not separately distinguished until Kümmel (1898) worked out the sequence of the Newark Group in New Jersey. Previously, Lyman (1895) had designated parts of what is now called Brunswick Lithofacies by the names "Lansdale," "Perkasie" and "Pottstown." The Lansdale was roughly the equivalent of the red shales below the Haycock sheet. The Perkasie included the ridge-making gray argillite member for which the name "Perkasie" has been retained in the present report and, in addition, a large amount of gray hornfels now recognized as metamorphosed red shale. The Pottstown was the approximate correlative of Brunswick red shales in the Quakertown basin. The name Brunswick was assigned by Kümmel from New Brunswick, New Jersey.

Both by lithology and stratigraphic position, the Brunswick Lithofacies is equivalent to Gettysburg shale in Adams, York and Lancaster Counties, Pennsylvania. The evidence of stratigraphic continuity and structure indicates that the Brunswick and Gettysburg shale were probably deposited nearly contemporaneously. Gettysburg shale continues into Maryland and, with a slight interruption, to the Potomac River. Bull Run shale in Virginia, directly along the strike of Gettysburg shale, is likewise the approximate equivalent of the Brunswick. Chicopee shale of the Connecticut Valley (Emerson, 1917, p. 96) is similar to the Brunswick, and like it, is at or near the top of the Newark Group. No accurate equivalence can be claimed, however, for reasons discussed below. In North Carolina the highest beds in the Durham basin are red sandstones similar to those of the Brunswick near the north border in Pennsylvania and New Jersey. Like the Brunswick, they pass into fanglomerate. They differ from Brunswick in containing some yellow arkose, like that of the Stockton Lithofacies. The highest beds in the Sanford and Wadesboro areas of North Carolina are similar.

The fish remains in New Jersey, Connecticut and Massachusetts are similar, but differ in detail (Newberry, 1888). At Boonton, New Jersey, fish beds are near the top of the series, above the Watchung lavas. and at Durham. Connecticut they are between the lava flows. Colbert (1946, p. 277) suggests a correlation of the First Watchung, Second Watchung, and Hook Mountain flows in New Jersey with the Anterior trap, Main trap, and Posterior trap, respectively, of Connecticut Valley. According to this scheme Chicopee Shale would be equivalent to a part of the Brunswick Lithofacies far above its base, and the entire series in Connecticut Valley might be of Brunswick age, in spite of the similarity of its lower member to the Stockton arkose. The dinosaur tracks in Gettysburg shale of York County (Hickock and Willard, 1933) are similar to the Connecticut Valley footprints, which occur above the lavas.

Correlation of the Brunswick shales with the Triassic of Europe has not been conclusively established. If the Lockatong lithofacies is the same age as the Lettenkohle, the Brunswick probably extends through the Keuper, perhaps including the Rhaetic of Germany and Great Britain. This is approximately the view of von Huene (1926) and of Colbert (1946, p. 270). Eastman (1905), however, on the basis of the fish fauna, correlated the Brunswick beds with the lower Keuper. Bock (1952) suggests equivalence with the Stubensandstein and Knollenmergel beds of the middle Keuper, with possible extension into the lower part of the Rhaetic (upper Keuper).

A correlation table for the Newark Group is given in Table 29. See also Reeside et al. (1957).

Stratigraphic relations

The relationship of the Brunswick and Lockatong Lithofacies has been described (p. 91). The main body of the Brunswick conformably overlies the main body of the Lockatong and widespread interfingering of the two facies occurs throughout a great thickness of strata.

To the west in Montgomery County, the shaly Brunswick Lithofacies grades along the strike into and interfingers with red sandstone. In Chester County the sandstone in turn grades westward into cobbly, quartz conglomerate (the Robeson conglomerate), which represents a great alluvial fan that persisted throughout most of the period of Brunswick sedimentation (McLaughlin, 1939).

The Brunswick Lithofacies includes the uppermost strata of the Newark Group, and it grades along the strike into the fanglomerates near the north border. The stratigraphic relations of the fanglomerate are discussed at greater length subsequently. Field evidence indicates that the fanglomerate of Flint Hill probably overlaps the Paleozoic limestone. From the northern tip of the Haycock diabase to the Delaware River and northeastward past Pattenburg, New Jersey, the border is so straight that a profound fault has been suggested. Near Clinton and Jutland, New Jersey, the fanglomerates lie upon lower Paleozoic limestone, and to the north the limestone floor is faulted down against Pre-Cambrian gneiss (Kümmel, 1898, p. 112; 1914, p. 104). Near Little York and Spring Mills, New Jersey, at the foot of the gneiss ridge, a narrow strip of limestone conglomerate lies parallel with a strip of Tomstown Dolomite from which the pebbles came (McLaughlin, 1946). Here the fault is a continuation of that north of Jutland, and separates Tomstown Dolomite from the gneiss, not the Triassic from Tomstown Dolomite. Some post-depositional movement along this or other faults seems to be required by the rather steep northward dip of the neighboring red shales.

At Holland Church, New Jersey, directly across the Delaware River from Monroe, limestone fanglomerate is exposed within a few rods of the southward-dipping Cambrian limestone that undoubtedly supplied the pebbles Fig. 10, p. 89). Hardyston Quartzite outcrops and float occur north of Cambrian limestone, and are in turn closely followed to the north by exposures of gneiss. Sheared limestone suggests faulting, probably local since it does not destroy the normal sequence of formations. If profound faulting occurred here it must have been largely before or during the Triassic. It involved down-faulting of the sub-Triassic floor, not of the rocks now exposed there.

Along the valley of the brook which flows into the Delaware River at Monroe, Hardyston Quartzite and gneiss are exposed in a small abandoned quarry along the south side of the brook and road at the

TABLE 29. *Correlation Table of the Newark Group for North Carolina, Virginia, Pennsylvania, New Jersey, Connecticut and Europe*

Deep River Coal Field, N. C.	*Richmond Basin Virginia*	*Adams and York Counties, Penna.*	*Berks and Chester Counties, Pa.*	*Bucks County Pennsylvania*	*New Jersey*	*Connecticut*	*Europe*
					Fanglomerate	Fanglomerate	RHAETIC ?
					Boonton fish beds	"Upper sandstones"	
					Hook Mountain basalt flow	Posterior trap flow	
Fanglomerate		Fanglomerate BENDERSVILLE basalt flow Gettysburg red shale Heidlersburg sandstone member Gettysburg red shale	Fanglomerate JACKSONWALD basalt flow Brunswick red shale and sandstone		Shales and sandstones	Posterior shales, with fish beds	
					Second Watchung flow	Main trap flow	
Sanford Formation (red shale and sandstone)	Otterdale Sandstone				Shales and sandstones	Anterior shales	
	Vinita Sandstone		Robeson conglomerate (alluvial fan)		First Watchung flow	Anterior trap flow	
Cumnock Formation (coal-bearing)	Black shale with *Estheria*	Conewago Hills conglomerate		Fanglomerate Brunswick Lithofacies, red shale	Brunswick Lithofacies, red shale and sandstone	"Lower sandstones" (arkose and conglomerate)	KEUPER
	Productive coal measures	Gettysburg shale		Lockatong Lithofacies, argillite	Lockatong Lithofacies, argillite	No Triassic sediments	LETTENKOHLE
Pekin Formation (red shale, arkose, and conglomerate)	Lower barren beds	New Oxord sandstone, arkose, and conglomerate	Stockton sandstone, arkose, and conglomerate	Stockton Lithofacies, sandstone, arkose and conglomerate	Stockton Lithofacies, sandstone, arkose and conglomerate		MUSCHELKALK
	Boscobel boulder bed		No Triassic sediments				

western edge of Monroe. These rocks are much disturbed, shattered and distorted. Above the quarry on the south, Cambrian limestone crops out, but its contact with the crystalline rocks is concealed. Cambrian limestone is in contact on the south with Triassic limestone conglomerate composed of relatively small, angular chips in red shale matrix. The limestone dips 42° SE. and strikes N. 77° E. The Triassic red beds strike N. 57° E. and dip 18° NW. Like Hardyston Quartzite, Cambrian limestone has been considerably distorted, so that the dip and strike readings have an appreciable range. The discordance of dips and strikes and the shattered conditions of the Paleozoic formations lends credence to the idea of a fault at this point. The Triassic limestone conglomerate is presumably derived from the Cambrian limestone. The sequence bears some analogy to the situation to the west at Franklin School. As such it appears that a gravity fault interpretation is probable. This is supported when the outcrops are traced westward along the valley. Cambrian limestone continues as a thin wedge between Triassic limestone conglomerate and Hardyston Quartzite for about half a mile to a point where the road zig-zags northwestward across the brook. A local resident stated that limestone was found here while cleaning out a spring. No limestone was discovered westward of that point along the probable trace of the fault.

The facts seem best explained in terms of down-faulting of the floor of the basin during deposition, after which the sediments in some places overlapped the older rocks to the north and concealed the fault. Some local, post-depositional faulting also occurred. In some places the floor probably shelved steeply, representing a slope against which the sediments accumulated. Such a relation has been demonstrated in Massachusetts, where the Mount Toby Conglomerate (fanglomerate) is exposed in unmistakable depositional contact against a steep, eroded scarp of crystalline rocks, with no evidence of a border fault (Bain, 1932).

Within the limits of Bucks County the only younger deposits that overlie the Brunswick red beds are gravels and alluvium of the Delaware River flood plain and float washed down from the hills in the northwestern part of Bucks County (Chapter V, p. 163). In contrast, at Tenmile Run Mountain northeast of Princeton, New Jersey, about 16 miles from Bucks County, the tilted and eroded Brunswick shale is overlain by the Upper Cretaceous Raritan Formation.

HISTORY OF TRIASSIC SEDIMENTATION

The hypothetical reconstruction of the history of deposition of the Newark Group in the outline given below is not uniquely established by the available facts. It is believed, however, that other possible interpretations would be similar to it in their essential features.

The main facts have been presented in detail in preceding sections They are broadly summarized in the introductory portions of Chapter IV, the Newark Group of eastern North America, and the Newark Group in Bucks County. However, specific mention should be made of a few points: (1) The floor on which the Newark Group was deposited was rather irregular; in particular, there is evidence that the

New Jersey and Connecticut areas were separate basins. (2) Extensive interfingering occurs between the Lockatong and Brunswick Lithofacies. The Lockatong Lithofacies was formed contemporaneously with the lower to middle part of the Brunswick. (3) The Stockton Lithofacies is in part contemporaneous with the lower Lockatong and, where the latter is absent, with lower Brunswick. However, the main part of the Stockton Lithofacies is the basal and oldest member of the Newark Group in the southern and central parts of the basin. (4) At some places younger beds of the Brunswick directly overlap the older rocks at the north border, with no Lockatong or Stockton intervening. The Brunswick, and in some places Lockatong and Stockton beds, pass into fanglomerate near the north border. (5) The materials that formed the Stockton arkose and conglomerate have been shown by Dellwig (1948) to be derived from the crystalline rocks south of the present outcrop of the Triassic. The Stockton red shales and sandstones, on the other hand, are interpreted by McLaughlin and Willard (1949) as having a northern origin in common with similar rocks of the Brunswick. Both westward and northeastward from Bucks County, Lockatong and Brunswick Lithofacies grade along the strike into sandstone and conglomerate. In Berks County a great thickness of conglomerate is interpreted as an alluvial fan that formed contemporaneously with the deposition of Lockatong and Brunswick in Bucks County (McLaughlin, 1939).

During the Appalachian orogeny in late Paleozoic time, the Paleozoic sediments and the underlying Pre-Cambrian rocks were folded and thrust-faulted. This disturbance affected approximately the eastern half of the State of Pennsylvania southeast of a diagonal from the northeast to the southwest corner. During late Permian and early Triassic time, the folded region was probably occupied by a lofty mountain range that was undergoing rapid erosion. By middle Triassic time, the mountain belt had been deeply eroded, especially in the southeastern corner of Pennsylvania, where the Pre-Cambrian rocks along the northwestern margin of the old land mass of Appalachia had been laid bare. One possibility that may be entertained is peneplanation of the region, followed by uplift, southeastward tilting, and renewed erosion. An alternative possibility appears to be that erosion did not proceed as far as peneplanation, but that by middle Triassic time the mountains had been maturely dissected. In either possibility, long, broad stream valleys had been eroded on the less resistant rocks, such as the Martinsburg shale, the Cambrian-Ordovician limestones, and some of the Cambrian and Pre-Cambrian phyllites and schists. The resistant quartzites of Cambrian and Silurian ages, and the granites and gneisses of the Pre-Cambrian, formed ridges or broad highlands with relief of several thousand feet.

The Silurian Shawangunk Formation supports Kittatinny Mountain in eastern Pennsylvania and New Jersey. The rock consists of gray to white quartzites and quartz conglomerates. The Green Pond Mountain syncline of north-central New Jersey extends southwestward to a point five miles northeast of Clinton, New Jersey. The Green Pond Formation underlying it occurs on the syncline southwest as far as

Flanders, New Jersey, which is about twenty-five miles northeast of Clinton. The Green Pond Formation, correlative of the Shawangunk Formation, consists in the north of whitish, gray, pink and red conglomerates, quartzites and sandstones. Southwestward, the red materials decrease so that at Flanders the formation appears to be nearly all gray and indistinguishable from the Shawangunk Formation. Turning westward into Pennsylvania a few small outliers of Tuscarora Quartzite or lower Shawangunk Formation are known south of Kittatinny Mountain between Schuylkill River and Swatara Creek.

Were the Green Pond Mountain syncline projected southwestward through Bucks County, it would extend approximately along the northern limit of the present Triassic. If we assume that in Triassic times a more or less continuous, even if attenuated, layer of Silurian sandstone, quartzite and conglomerate blanketed Northampton and Lehigh Counties and adjacent parts of New Jersey, it might have been the source of the siliceous pebbles in all of the fanglomerates. The lithology of the pebbles is similar to those of both the Shawangunk and Green Pond Formations. Of this it is worth recording that at Flanders some of the Silurian beds have a peculiar pitted appearance suggestive of fine tubes or worm borings. A pebble of such was found near Clinton in the fanglomerate.

If the Silurian pebbles were distributed in Triassic times as postulated, there must have been relative vertical movement, downward for the Triassic basin and upward for the older rocks along the border, to keep up the supply for the fanglomerates. This assumption is unavoidable because of the continuous deposition of the conglomerates throughout Newark time in the Hunterdon Plateau region. As the movement was confined to such a narrow band, it lends strength to the fault concept. With repeated or continuous movement, the older fanglomerates dropped down and were overwhelmed by the later, but each successively passed basinward into red beds, and the older in turn into the Stockton and Lockatong Lithofacies.

At the center of the basin Stockton arkose accumulated to a depth of about 5,000 feet (including interbedded red sediments), and thinned towards both the southern provenance and towards the northern margin. Younger beds overlapped the older toward the south and also to the southwest, where a structural high, the present Honeybrook upland, jutted into the valley and remained above the level of sedimentation through more than two-thirds of the period of Stockton deposition.

Not all of the sediments came from the south during deposition of the Stockton Lithofacies. Torrential streams issued from the northern escarpment carrying considerable amounts of sediment. But at this early stage, no major stream had yet breached the escarpment. The resistant quartzite ridge established a temporary base level which prevented lowering of the thick series of younger sediments north of it. On the peneplane that developed there, a mantle of red sediment accumulated from the red sandstones and shales of Silurian, Devonian and Mississippian ages. During deposition of the Stockton Lithofacies, a number of streams worked headward through the escarpment and began to tap this source of red sediments. From bottom to top of the

Stockton, especially in the northern belt, increasing amounts of red sandstone and shale are interbedded with the arkose. The center of the basin (northern belt of Stockton Lithofacies) thus exhibits an interbedding and interfingering of southern arkosic "Stockton Lithofacies" rocks with northern "Brunswick Lithofacies type" red beds.

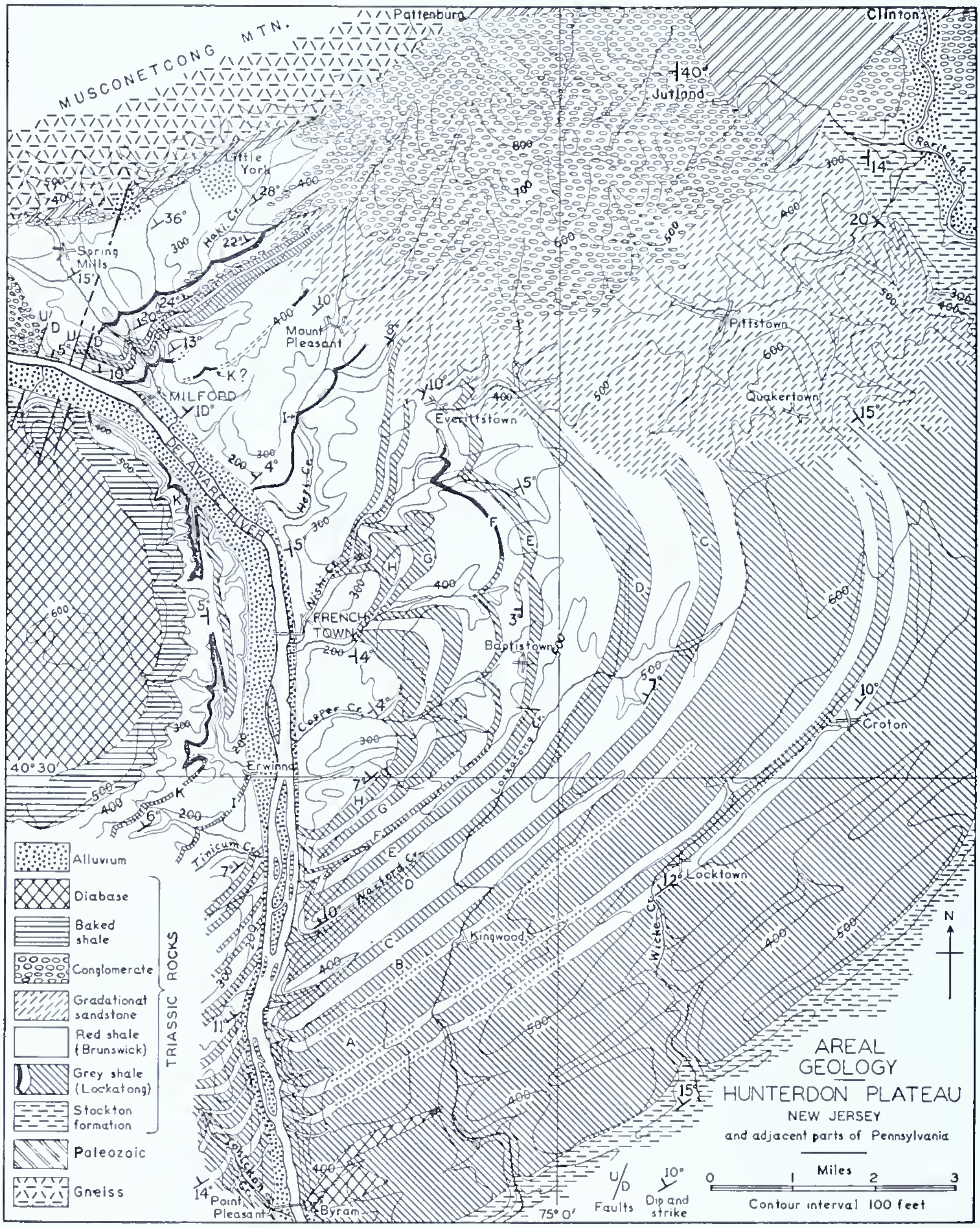
By the end of Stockton deposition the southern highland had been eroded to such low relief and the valley had been filled so deeply that deposition of arkose ceased in the center of the basin, though it probably continued at the southern margin which has since been removed by erosion. With the filling of the basin, the small torrential streams from the north debouched upon a flat valley in which the drainage had become sluggish. To this statement we note one exception: a larger stream that we may call the ancestral Schuylkill had at last breached the escarpment of Silurian quartzite and had begun to deposit a thick series of gravels and sands in a great alluvial fan whose apex was near the present site of Reading. But its influence had not yet made itself felt in the area of Bucks County.

The center of the basin, remote from either northern or southern supplies of sediment, now became a swamp or a broad, shallow, freshwater lake which received only the finest of muds. Plants, fish, crustaceans and molluscs inhabited the region, and carbonaceous residues accumulated (Stevenson, 1948). In the reducing environment, red ferric oxide in the muds from the north was changed to ferrous compounds. Under these conditions the Lockatong Lithofacies accumulated. That the lake bed frequently became dry is attested by the abundance of mud cracks at all horizons in the Lockatong. The limits of the area of black shale and argillite deposition were determined by the encroachment of sediments that came from the ancestral Schuylkill to the west and the highlands to the northeast.

The numerous smaller streams that entered the basin from the north contributed a considerable volume of sediment, but the turbulent waters did not encroach far upon the Lockatong lake. The Lockatong argillite in northern Hunterdon County, New Jersey, retains its typical character to within 8 miles of the northern border. The character of the rock changes between six to eight miles from the border (Fig. 14, p. 112), as a large alluvial fan about Pattenburg lies directly on its strike. Other streams that entered from the north formed smaller deposits of fanglomerate and must have had less influence upon the Lockatong sedimentation.

Under the thickening load of sediments the basin began to subside by faulting at the north border and the northern highland rose as it was eroded. Recurrent faulting throughout the remainder of Newark time renewed the stream gradients again and again, while the escarpment was eroded back toward the north. As the ancestral Schuylkill River deepened its gorge, the volume of red sediments from the north increased. From the mouth of the gorge near Reading, the muds were spread out for many miles to the south, west, and east. Sand was carried to distances of 25 miles, and gravels for 15 miles and locally farther. Other streams, too, increased in volume and built alluvial fans at the north border. Many oscillations between swamp or lacus-

Figure 14



Sketch map of Hunterdon Plateau, N. J., showing passage along strike of Triassic lithofacies into border fanglomerate.

trine conditions and fluvial or torrential deposition are recorded in the alternation and interfingering of black and red shales in the upper part of the Lockatong in the Delaware Valley. Finally the supply of red muds from the north became so copious that it overwhelmed the basin entirely and brought to an end the deposition of the Lockatong Lithofacies in lakes and swamps, except for a few brief recurrences that are recorded by gray shales higher in the Brunswick section.

One feature of the distribution of red and black shales that calls for special mention is the relative thinness of the Lockatong section in the southern belt. This is attributed to a combination of causes. In the first place, the author believes that the center of the basin subsided more than the borders, and for this reason a greater thickness of Lockatong argillite could be deposited. Secondly, the most probable correlation of strata in the southern and northern belts (Table 26, p. 103) indicates that dominant red shale deposition began earlier in the south than in the north. This may at first appear difficult to reconcile with a northern source of the red muds. Had they come directly across the basin from the northern border, the quiet deposition of Lockatong sediments in lake or swamp would have prevailed until later in the south. Thus, if red muds had been transported directly southward in large quantities from the northern border near Monroe, we should now find thick interbeds of red shale at a lower horizon in the northern belt of Lockatong than in the southern, and gray argillite deposition would have ceased earlier in the northern belt than in the southern. Actually, the situation is the reverse of that stated.

The facts are satisfied by the hypothesis that during late Lockatong sedimentation the torrential, ancestral Schuylkill to the west was the largest source of sediments for the southern part of the Bucks County area. Muds, sands and gravels were washed nearly across the Berks County portion of the basin from north to south or southeast. Then, fine red muds were carried eastward and northeastward by sluggish streams that flowed near the southern edge of the basin. In this way, while the environment for Lockatong deposition continued in Bucks County in the central part of the basin, it was inhibited in the south. The region least affected by the supply of muds from the fan of the ancestral Schuylkill River was not the central part of the basin, but somewhat to the north of the center, approximately where Point Pleasant is now located.

Near the close of Brunswick deposition, three thick lava flows poured over the surface of the basin in New Jersey. Extensions of one or more of them may have spread into Bucks County, for a basalt flow is exposed at Sand Brook, New Jersey, about five miles from the Delaware River. A lava flow is also known at Jacksonwald in Berks County to the west. The thick sheets of diabase and the dikes may have been intruded simultaneously with the surface outpourings of lava, or they may have been formed at an earlier or later date. Some deformation probably accompanied the intrusion. Haycock Mountain appears to be a laccolith-like thickening of a sheet. It occupies a plunging syncline in the shales, as if the strata had subsided beneath the igneous rock. The basin-like structure of the rocks beneath the Coffman Hill sheet may have had a similar origin.

The thickness of the Newark Group at the center of the basin is estimated at approximately 12,000 feet before block faulting and erosion (McLaughlin and Willard, 1949, p. 43). This figure is far below the sum of the separate thicknesses, 17,700 feet, recorded for the three lithofacies, which includes the thick series of Brunswick shales above the Haycock sheet. Even the total apparent thickness exposed below the Haycock sheet exceeds 12,000 feet. However, it is believed that a boring through the Triassic sediments from a point near the foot of Haycock Mountain would encounter considerably less than 12,000 feet of Triassic strata. Just as the Stockton Lithofacies thins toward its southern provenance, so it is believed the Brunswick thins towards its northern source. Moreover, the floor of the basin probably shelved northward and received no sediments within several miles of the northern border until after at least a few thousand feet of arkose had accumulated in the central region, where the greatest thickness of Stockton Lithofacies is now exposed. Fanglomerates that interfinger with shales at a high horizon in the Brunswick section are in direct contact with the pre-Triassic floor at some points along the north border, notably north of Gladstone, New Jersey (Kümmel, 1898, p. 114), at Flint Hill in northern Bucks County and at adjacent localities in Lehigh County (Wherry, 1941). A steep shelving of the floor is indicated east and west of Pattenburg, New Jersey, where Stockton, Lockatong, and Brunswick Lithofacies successively overlap the Paleozoic shales and limestones (Fig. 14, p. 112).

After the sheets and dikes had solidified, the rocks of the Newark Group were broken by several great faults, and the resulting blocks were tilted to the northwest, impressing on the strata their present regional dip. If these dislocations occurred rapidly, they must have produced a range of fault-block mountains with a relief of several thousand feet. At the same time further movements probably occurred along the faults at the north border, and a number of minor faults were formed.

During Jurassic time the region was subjected to continuous erosion. By early Cretaceous time, the tilted Triassic rocks had been peneplaned. The Cretaceous sea transgressed neighboring areas of New Jersey, and sediments of that age probably covered the southern part of Bucks County. All definite traces of its deposits have been eroded from or are concealed within the limits of Bucks County.

TRIASSIC LIFE

by

EDGAR T. WHERRY

The Newark strata are poor in fossils, yet when the data from scattered localities are assembled, a fairly rich fauna and flora prove to have inhabited the basin. The points where collections have been made are marked "F" on the geologic map of Bucks County (Plate 2, in pocket).

Plants

THALLOPHYTA: Algae

Various types of algae grew in the waters from which the sedimentary rocks of Newark Group were deposited, and their impressions or casts are preserved in the finer-grained strata at many places. They range from delicate filaments (Plate 15, A)* to cylindrical objects up to an

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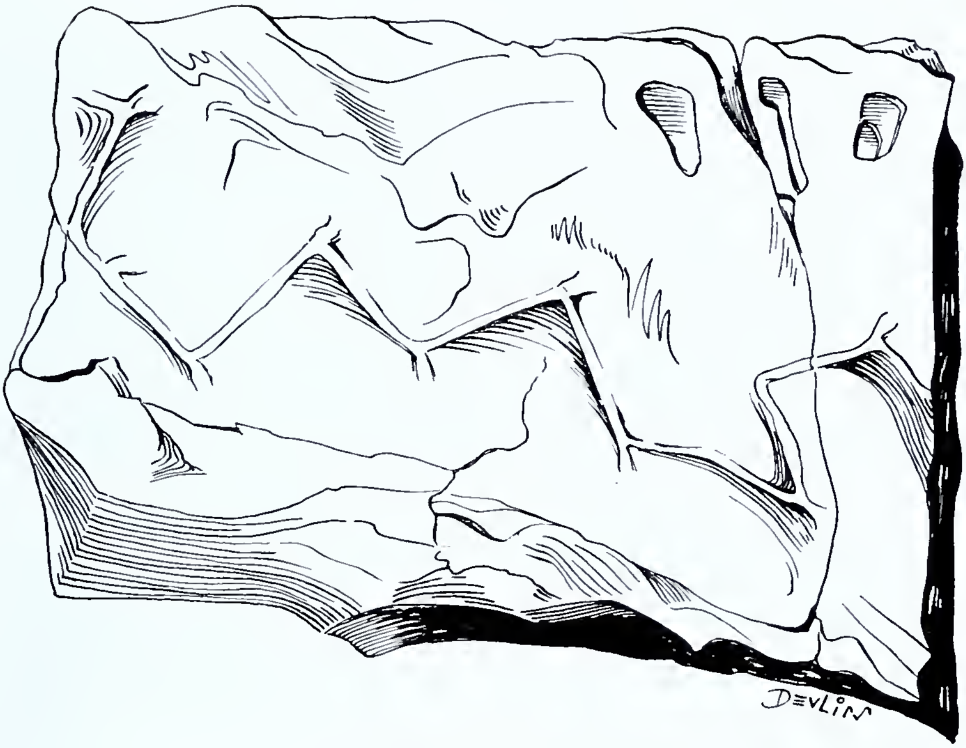
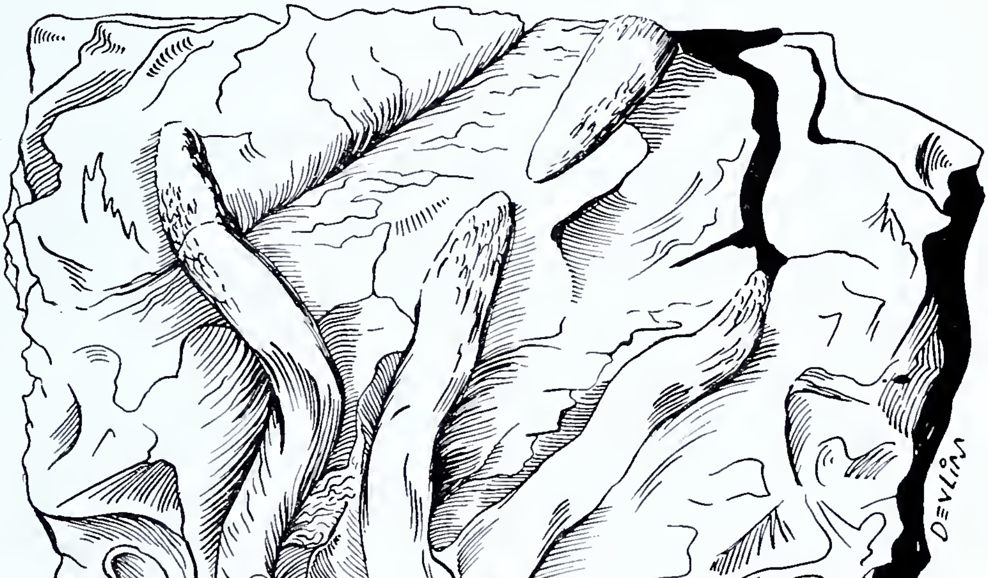
* Drawings of plant fossils were contributed by Mr. Joseph M. Devlin of the University of Pennsylvania. Thanks are due to Mr. Wilhelm Bock for the loan of specimens and for aid in nomenclatorial problems.

PLATE 15



A. Filaments of algae.



B. Algae, showing spore-bearing branchlets.

inch in diameter and several inches long. The latter are known, in reference to their general aspect, as finger-algae, and are assigned to the family Dasycladaceae. The body or thallus grew more or less erect, and was surrounded by dense whorls of tiny branchlets, on which spores were borne (Plate 15, B). They formed beds in the muddy water of playa lakes, and kept growing as mud deposited around them until the lake dried up. Then they died and disintegrated, leaving cylindrical hollows in the hardening sediment, which would be filled by coarser material when water came in again and formed another lake. Persisting spores could then start another colony, and the process would be repeated again and again. Their casts can now be found wherever fine-grained strata are exposed. On bedding surfaces they appear as rough disks, mostly one-eighth to one-half inch in diameter; where the rocks fracture across the bedding, they resemble aggregates of worms, but their true nature is shown by the presence of branchlets.

TRACHEOPHYTA: Sphenopsida

Although living horsetails are rather small plants, some of their Triassic ancestors attained tree stature. One notable occurrence of these is known in Bucks County, in the soft red shales of Stockton Lithofacies which crop out northwest of Holicong. Here are preserved stem-casts up to a foot in diameter and 20 feet or more in length, with the longitudinal striations characteristic of this plant group. Although no reproductive structures have as yet been discovered, slender branchlets are found among these casts (Plate 16, A).

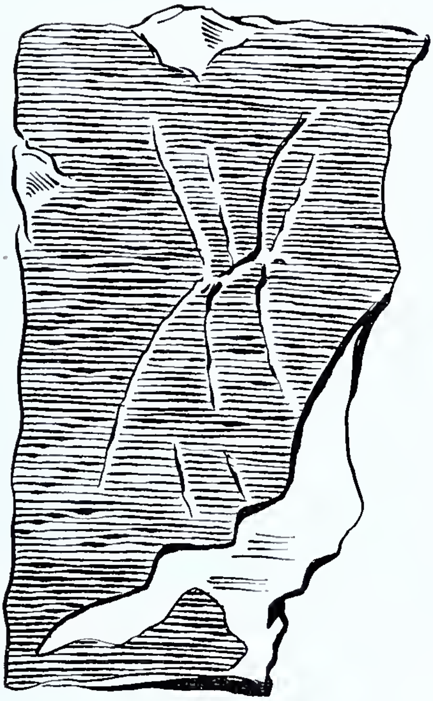
This plant was first made known to science in 1885, and has been successively identified as *Calamites arenaceus*, *Schizoneura laticostata*, *S. planicostata*, and *Equisetum rogersii*. Actually it differs in many respects from all of these, and probably belongs to the genus *Mesocalamites*.

A different member of the same group occurs sparingly in the fossil-rich, dark-gray, micaceous shales of Stockton Lithofacies exposed in the now abandoned quarry one-fourth mile northeast of Carversville. This fossil consists of a slender striated stem at nodes of which are whorls of linear leaves an inch or more in length (Plate 16, B). This is *Neocalamites* (Halle, 1908), and there seem to be two distinct species present.

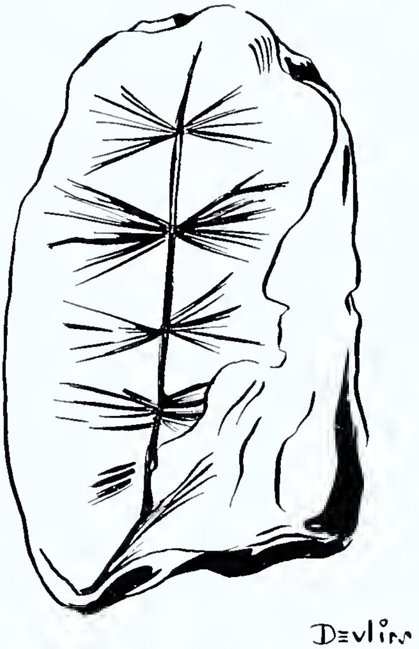
Pteropsida: Filicales

Although several sorts of higher groups of plants preserved in the Triassic rocks of Bucks County have a fern-like aspect, the solitary representative of this group found does not look like any familiar fern. It consists of a strap-shaped, entire blade up to 2 inches across and a foot or so in length. Most remarkable is its thickness which even in its compressed, fossilized state is ⅛ inch, and may have been greater in life. In shape it resembles the leaves of the cycad *Taeniopteris*, but its venation is entirely different: from an obscure midrib numerous fine, repeatedly forked veins diverge at acute angles. It seems to represent an as yet undescribed genus (Plate 16, C).

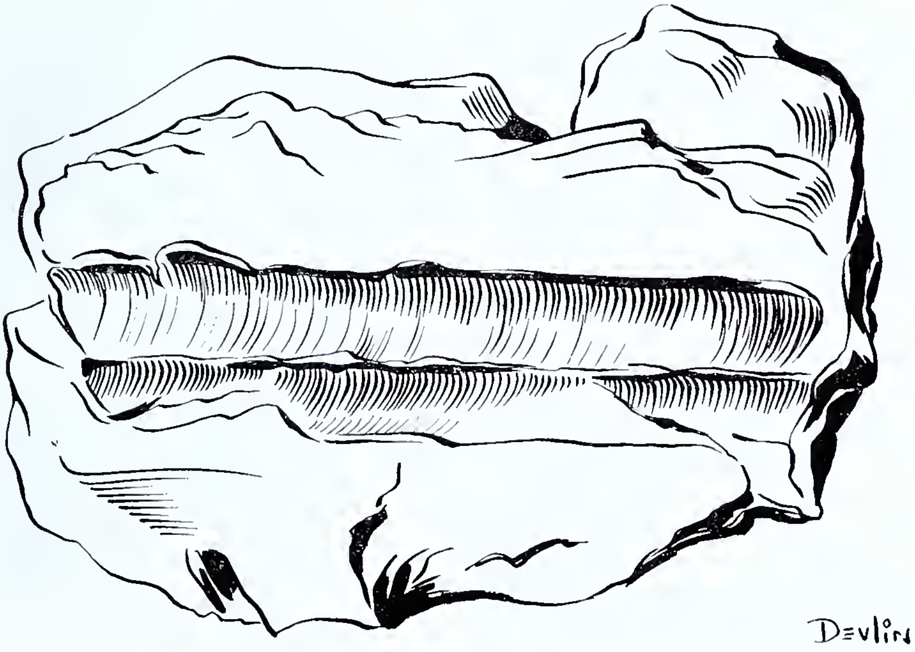
PLATE 16



A. Slender branchlet of horsetail, red shale, northwest of Holicong.

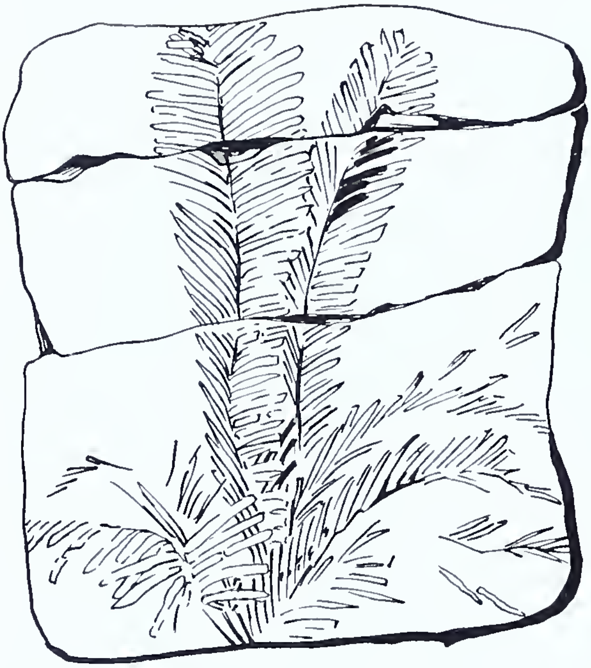


B. *Neocalamites* sp., gray shale, ¼ mile northeast of Carversville.

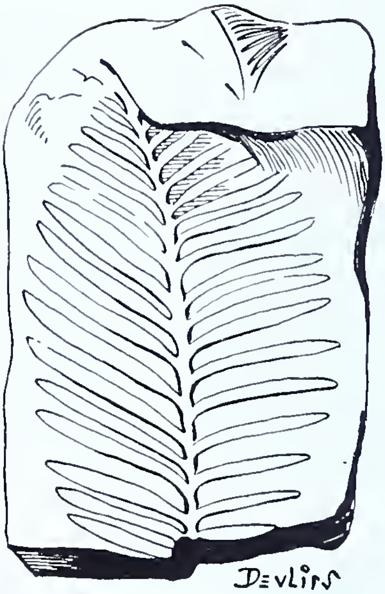


C. Filicales leaf, gray shale, ¼ mile northeast of Carversville.

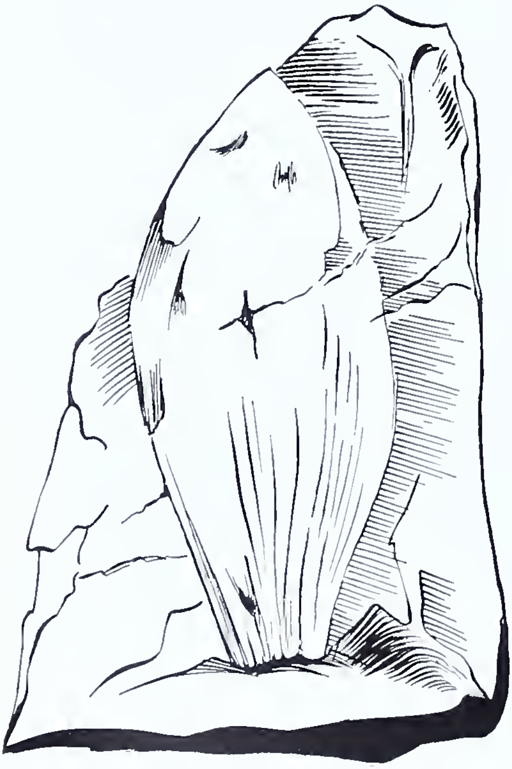
Plate 17



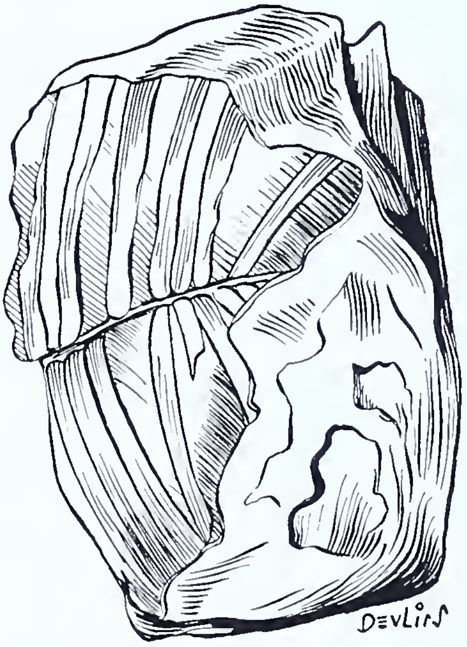
A. *Podozamites* sp., gray shale, ¼ mile northeast of Carversville.



B. *Pterophyllum* sp., gray shale, ¼ mile northeast of Carversville.



C. *Otozamites* sp., gray shale, ¼ mile northeast of Carversville.



D. *Ptilophyllum* sp., gray shale, ¼ mile northeast of Carversville.

The unusual thickness of the fronds of this plant suggests that it was adapted to growth under rather dry conditions. It may have inhabited barren rocky slopes adjoining the Newark basin, and been washed into the swampland where the Carversville beds accumulated.

GYMNOSPERMAE: Cycadales

Many years ago an impression of a small cycad leaf was found in red shale of Stockton Lithofacies at the locality northwest of Holicong. It was considered by Knowlton and White (Bascom and others, 1931, Plate 4 B) to represent *Cycadites cf. tenuinervis.*

The strata of Stockton Lithofacies northeast of Carversville contain numerous cycad remains, comprising leaf-fragments, whole leaves, and in one place a complete plant. This locality was discovered in the early 1900's, when the township opened a small quarry for crushed stone for road improvement needed by growing automobile traffic. Brown (1911) described several species from there, naming one well-preserved cycad leaf *Zamites velderi* in honor of the local resident who brought the occurrence to the attention of the staff at the Academy of Natural Sciences of Philadelphia. This leaf, now in the Academy collection, belongs to the genus *Otozamites.*

Two other cycad leaves were assigned by Brown to *Podozamites* (an intermediate between cycads and conifers), but further study indicates these also represent species of *Otozamites,* a more typical cycad. The complete plant, which was obtained there during the course of subsequent excavations by Wilhelm Bock, is still another member of the same genus.

Material obtained by Bock also includes species of *Pterophyllum* (Plate 17, B), *Ptilophyllum* (Plate 17, D), *Podozamites* (Plate 17, A) and *Nilssonia* (Plate 18, A). The last genus was not known previously in strata as old as Triassic.

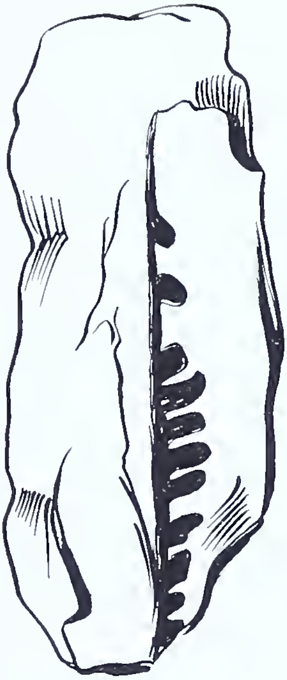
In the Reading Railroad cut through dark-gray shale of the Brunswick Lithofacies a mile south of Sellersville there is exposed a stratum containing impressions of slender leaves or leaflets in crowded assemblages. When studied by the writer (Wherry, 1916), this plant was assigned the genus name *Brunswickia* in reference to its occurrence in the Brunswick Lithofacies of the Newark Group, and the species name *dubia* because of uncertainty as to its relationship. Subsequent study of the material suggests that it represents masses of leaflets of a member of the cycad genus *Pterophyllum.*

Coniferales

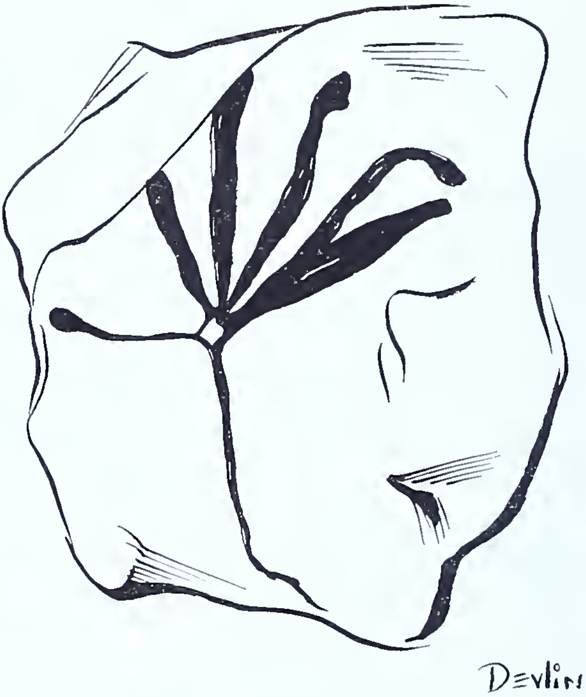
Of the three lithofacies of the Newark Group in this region, the arkosic sandstone of the Stockton Lithofacies, in which there are abundant grains of feldspar, mica, and quartz, indicates that the climate was drier than at present.

Disintegration outstripped decomposition so that these rock-making minerals crumbled into fragments. The streams which brought these minerals into the Newark basin also floated down tree trunks, which upon becoming water-logged were embedded in the sand deposits. Percolating waters then liberated colloidal silica from the various

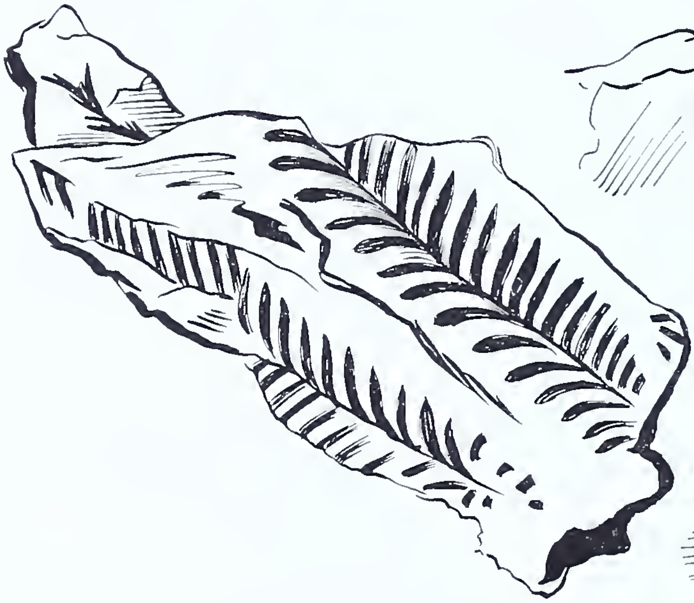
Plate 18



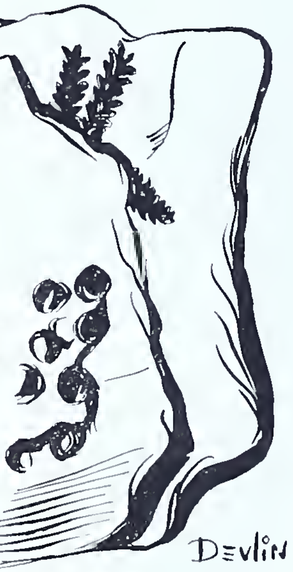
A. *Nilssonia* sp., gray shale, ¼ mile northeast of Carversville.



B. Ginkgo leaf, dark-gray shale, ¼ mile northeast of Carversville.



C. *Palissya longifolia* Wherry, gray shale, ¼ mile northeast of Carversville.



D. Seeds of araucarian conifer, gray shale, ¼ mile northeast of Carversville.

silicates, which replaced the tissues of the wood in such a way that every detail of structure was preserved.

Subsequent uplift and erosion has liberated pieces of such silicified wood in fields, gullies, and stream beds (Wherry, 1912b). They are dull in luster, and have the appearance of weathered pieces of wood, although when lifted or struck, their petrified condition is evident.

The writer collected specimens of silicified wood from a number of localities in Bucks County and other southeastern Pennsylvania counties, and prepared microscopic sections of them. The presence of three species was determined (1912b). Two showed the close-set, bordered pits characteristic of Araucarian conifers. One of these was identical with *Araucarioxylon virginianum,* described from Virginia. The other had more numerous uniseriate pits and was named *A. vanartsdaleni.*

A third type of wood showed the more widely spaced and variable pits characterizing the genus *Brachyphyllum.* This type of wood, found in Cretaceous strata, was named *Brachyoxylon* by Hollick and Jeffrey in 1909. Although such wood had not previously been reported from as early as the Triassic, the local material was named *Brachyoxylon pennsylvanianum.*

The trees which yielded these logs evidently grew many miles away in the uplands adjoining the Newark basin. In the course of transportation and deposition their foliage and fruiting structures were destroyed. The carbonized fragments which occur in the adjoining strata are unidentifiable. However, seeds of both araucarian and brachyphyllan relationship have been found by Bock at a higher horizon elsewhere in Bucks County.

A considerable number of conifers evidently grew in or close by the swamp in which the strata of Stockton Lithofacies now exposed at Carversville were deposited. Many branches, leaves and reproductive structures fell into the mud and were preserved there. Brown (1911) described four of these, two considered to be the same as species previously found in the Triassic, and two new ones. The former two were assigned to the genus *Cheirolepis,* but subsequent detailed study shows these to have the seed characters of araucarian conifers instead (Plate 18, D). The other two were placed in *Palissya,* but these also need reclassification. According to more modern views of the interrelations of this plant group, all four should be classed as belonging in "*Pagiophyllum*". Another Carversville species was named *Palissya longifolia* by the present writer, but it also is now regarded as belonging in the *Taxus* group (Plate 18, C).

In 1932 a solitary, poorly preserved cone was found in the beds 1 mile south of Sellersville where the cycad leaves occur. All that could be stated (Wherry, 1933) concerning it was that it had a resemblance to "*Strobilites taxus*" from the Triassic of South Africa.

Ginkgoales

One of the most unique fossils found in the beds at Carversville is a leaf which is divided into 5 or 7 long, narrow, upwardly expanded leaflets in a palmato-pinnate arrangement (Plate 18, B). These leaflets are veined so like the leaves of our modern ginkgo that assignment to this plant order is indicated. It differs from the widespread primitive genus of this order, *Baiera,* in that the leaflets are distinct and not forked. It appears to represent an undescribed genus, and that two or three species existed is shown by differences in size. In some specimens the leaflets reach 7 inches in length, in others only two inches (Bock, 1952).

Animals

INVERTEBRATA: Vermes

Although the casts of finger-algae discussed above have been referred to by writers on the Triassic as "worm-holes", their algal nature is shown by the whorls of branchlets at nodes. That worms were present during the Triassic is shown by the presence in a few places of tracks on shale bedding surfaces.

Mollusca

The occurrence of fresh-water shells of the genus *Unio* in Triassic rocks of Pennsylvania has been recognized. The only known find of these in Bucks County, however, consists of a single cast in the black beds of Stockton Lithofacies at Carversville.

On one slab of shale obtained by Bock at this locality there is a meandering groove looking like the impression of a string of tiny beads. This apparently represents the track of a snail, but no other remains of such an organism have been found.

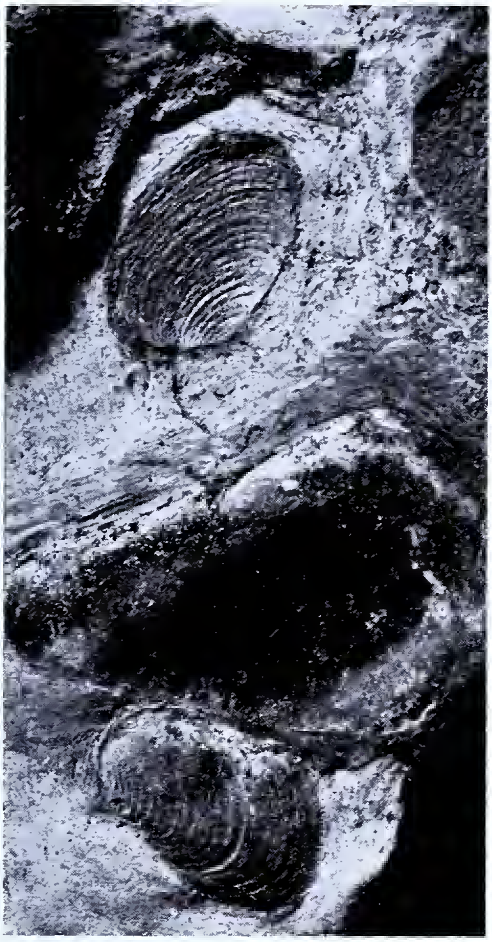
Crustacea

The organisms known as estheriïds, which thrive in water containing decaying organic matter, were abundant in the pools from which the dark-gray beds of Lockatong Lithofacies were deposited. Impressions of their valves are found at numerous exposures. The commonest type, an obliquely oval disk about one-quarter of an inch long, with prominent concentric grooves (Plate 19, A) has in the past been named *Estheria ovata.* The genus name *Estheria* has been used earlier in another sense, however, so this organism should be called *Isaura ovata.* Smaller species, which have radial striae in addition to concentric ridges, are assigned to the genus *Estheriella.* There are also tiny valves preserved in some beds which apparently represent one of the fresh-water types of cyprid crustaceans or ostracods (Bock, 1953).

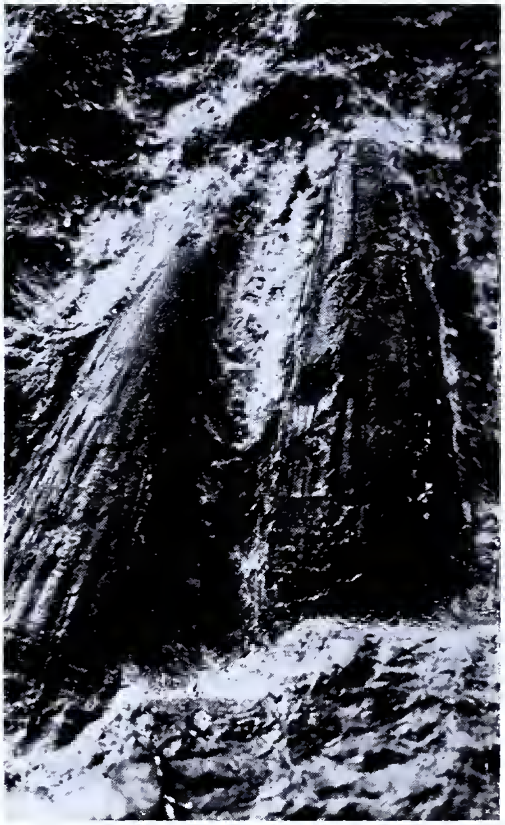
VERTEBRATA: Pisces

Fishes lived in the waters from which the beds of Lockatong Lithofacies were deposited. That they fed upon the crustacea which abounded in the humus-rich water is shown by the preservation in the strata of coprolites, in which broken-up crustacean valves can be discerned. Isolated scales of the fishes are of frequent occurrence, and at the quarry southwest of Tradesville more or less complete

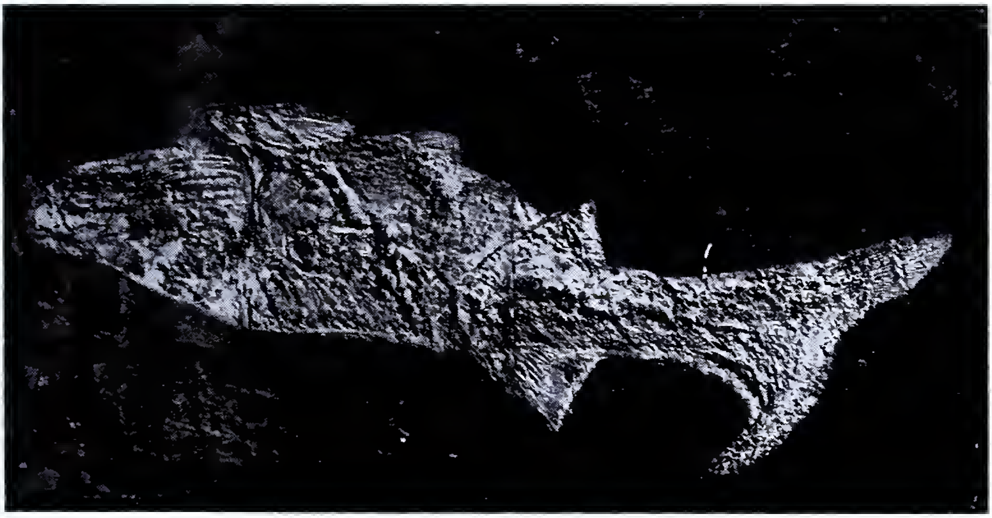
PLATE 19



A. *Isaura ovata* (Lea), Lockatong gray argillite.



B. *Clepsysaurus sp.*, teeth, Lockatong argillite, Tradesville.



C. Fish, Lockatong gray argillite, Tradesville.

specimens are occasionally found; one of these is illustrated (Plate 19, C). Three species have been recognized. One, *Osteopleurus newarki,* is a coelacanth, showing development of bony ribs. Another, *Redfieldius redfieldi,* is a subholostean primitive fresh-water type of ganoid. The third, *Semionotus ovatus,* belongs in a group designated the semionotids; others remain to be described.

In the quarry at Rushland have been found scales and a fin of another coelacanth, *Rhabdiolepis longicaudatus,* the largest known fish of the Newark Group.

Reptilia

That reptiles lived in the region where beds of the Newark Group were laid down is proved by their footprints preserved on shale surfaces. One of these, made by a *Cheirotherium* (Hitchcock, 1889), was found in a quarry in Lockatong Lithofacies southeast of Washington Crossing many years ago. (Plate 20 represents a similar one from New Jersey.) Actual remains of the creature have never been found (Bock, 1952).

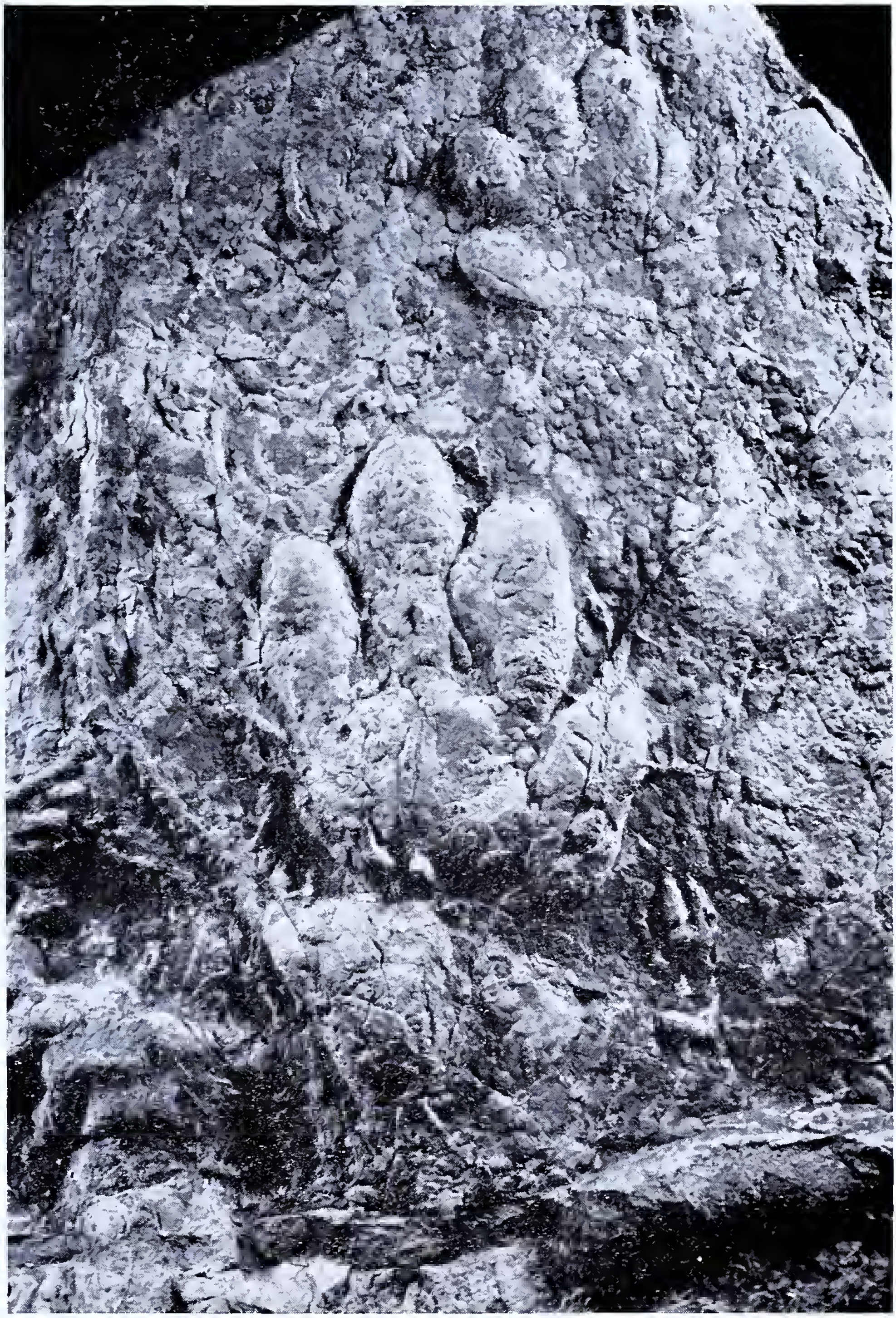
A smaller footprint, found between Kintnersville and Ferndale, was described by Ryan and Willard (1947) as *Kintneria brunswickii,* and regarded as amphibian. The impressions show, however, sufficient evidence of the presence of claws to suggest that it was a lacertoid reptile. Additional tracks of a similar organism have been obtained in quarries southwest of Durham.

Actual remains of reptiles are disappointingly scarce in Bucks County. In beds of Stockton Lithofacies with plants near Holicong, a jaw was found many years ago and named *Calamops paludosus.* This was considered to be an amphibian (Sinclair, 1917), but could just as well have been a reptile. On Plate 19, B are illustrated teeth found in the Tradesville quarry in Lockatong Lithofacies referable to the long-known *Clepsysaurus pennsylvanicus,* a crocodile-like animal which is better represented by fossils from adjacent counties. Very recently a jaw bone with numerous teeth attached was found in the quarry near Tradesville, but this has not yet been sufficiently studied to establish whether it is a reptile or not.

Age and Correlation

None of the fossils listed is older than the Keuper, the youngest of the three divisions of the German Triassic (Keuper, Muschelkalk, Buntersandstein). Most probably the deposition of Stockton Lithofacies began with the Lettenkohle (Table 29, p. 107). Lockatong Lithofacies corresponds fairly closely with the Gipskeuper, which represents the middle part of the Keuper Formation (Chapter IV, p. 107, and Table 29, p. 107). Brunswick Lithofacies may have begun depositing in the late middle Keuper time, and continued into the upper Keuper or Rhaetic (Chapter IV, Table 29, p. 107).

Plate 20



Cheirotherium sp., Milford, New Jersey.

STRUCTURE OF THE TRIASSIC ROCKS

by

DEAN B. MCLAUGHLIN

General

Throughout a large part of the area of Triassic rocks in Bucks County the bedding dips northwesterly or northerly at low angles, rarely as much as 20 degrees. Superimposed on this homocline are broad warpings and some sharper flexures that form anticlines and synclines with axes transverse to the prevailing strike of the beds. A few large, normal faults, oblique to the strike at many places but nearly coincident with it in others, repeat considerable parts of the Newark Group, and numerous faults of small displacements are known. The main structural features of the Triassic rocks in Bucks County and adjoining areas are shown in Figure 15.

Folding

Jericho syncline

The hook-like form of the ridge of Jericho Mountain at the east-central side of Bucks County suggests a synclinal fold of the diabase sheet. This is confirmed by the dips of the enclosing shales, so far as they are exposed. Moderate southwest dips occur west of the northern tip of the ridge, while northerly dips are the rule north and south of its western part. The synclinal axis, trending about N.75°W., is cut off at the west by the Buckmanville fault. The shales for more than three miles southeast, south and southwest of Jericho Mountain exhibit a gradually curving strike that is roughly concentric to the narrower curve of the trap ridge. However, the diabase is not everywhere conformable to the shale.

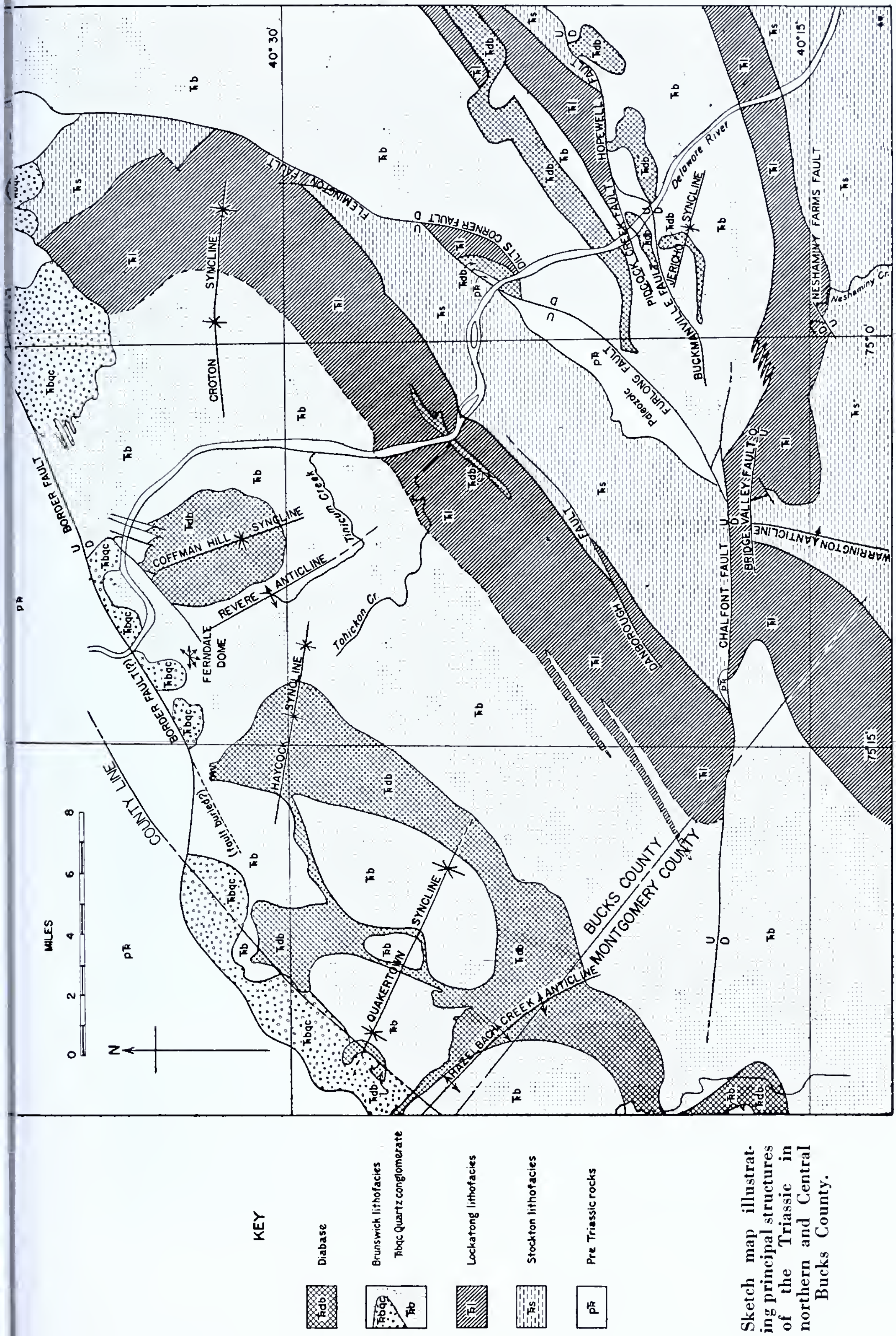
Warrington anticline

The Warrington anticline in the southwestern part of Bucks County causes the boundary between Stockton and Lockatong Lithofacies to curve sharply from westward to northward about a mile north of Hartsville. West of Warrington the boundary trends southwestward. Exposures of Stockton sandstones are scarce, but the boundary and the dips of the overlying Lockatong argillite define the axis approximately. It strikes N.10°E. A diabase dike comes to the surface close to the axis. This suggests a possibility that induration of the sandstone by contact metamorphism may have been a factor in the establishment of the anticline when the less rigid rock on both sides subsided. The anticline is cut off at the north by the Bridge Valley fault.

Coffman Hill syncline

The Coffman Hill diabase sheet occupies an elliptical area near the northeastern corner of Bucks County. The surrounding shales that underlie the diabase dip gently toward it from the east, south and west. The synclinal axis trends N.20°W. and plunges very slightly

GURE 15



Sketch map illustrating principal structures of the Triassic in northern and Central Bucks County.

northwestward. Along the Delaware River northwest of Coffman Hill, diverse low dips show gentle minor anticlines and synclines superimposed on the major structure (Fig. 13, p. 101). The northern limb is complicated by local normal faulting.

Revere anticline

Northwest and south of Revere in the northeastern part of Bucks County a gentle anticline separates the Coffman Hill area from that of Haycock Mountain (Fig. 13, p. 101). The axis trends approximately N.30°W. The shales east of the axis dip eastward and northeastward towards Coffman Hill. West of the axis, dips are west and southwestward toward Haycock Mountain. A slight effect of this structure is still evident several miles to the southeast near Ralph Stover Park. A small but definite change of strike occurs in Lockatong argillite near the great loop meander of Tohickon Creek (Figure 9, p. 88). West of the loop the strike is N.55°E. and east of the loop it is N.62°E. The axis reaches the Delaware River near Lumberville, and there is an appreciable change of strike of the Stockton-Lockatong contact at the Delaware River.

Ferndale dome

On the northward extension of the Revere anticline, the shales dip outward at angles of about 10 degrees from a center approximately one mile northwest of Ferndale (Fig. 13, p. 101). Inasmuch as no northwesterly dips have been observed, the structure may not be a complete dome. Outcrops are lacking in the area of fanglomerate that occupies that limb. The east limb of the dome is cut by two normal faults or fault zones with northeasterly strike.

Kintnersville to Monroe

Undulations of the beds occur along U. S. Route No. 611 between Kintnersville and Monroe in northeastern Bucks County. All the dips are gentle, with a maximum at Monroe where the fanglomerate and sandstone dip northward approximately 20 degrees. The structure in this section can be approximately described as consisting of a gentle anticline, with axis striking northeastward across U. S. Route No. 611 about 400 yards south of Monroe. This anticline is followed to the south by a broad open syncline whose axis strikes northeastward and crosses the road about 600 yards north of its junction with State Highway No. 32.

Haycock syncline

East of Haycock Mountain the strike of the gently dipping shale and hornfels curves around from northeasterly to northwesterly. This defines a syncline whose axis trends roughly N.80°W. and plunges westward. On the northeast limb east of Pleasant Valley, dips as high as 30 degrees occur, but the syncline dies out quickly near Pleasant Valley and simply merges with the homoclinal northwest dip. The deformation may have been caused in part by the intrusion.

Quakertown syncline

Northeast of Quakertown the shale dips to the northwest; southwest of the town it dips to the north. Due west of Quakertown, in the neighborhood of Spinnerstown, northeasterly dips are as high as 28 degrees, while at Steinsburg and east of there the dips are gently southwestward. The Quakertown synclinal axis passes about three-fourths of a mile south of Steinsburg and an equal distance south of Quakertown, trending N.65°W. and plunging northwestward. The syncline is asymmetrical, with the steeper limb to the southwest. The northeast limb is ill-defined, owing to scarcity of outcrops and to extensive diabase intrusions about Shelly. To the northeast the syncline probably merges with the general homocline, as does the neighboring Haycock syncline.

Hazelbach Creek anticline

The Hazelbach Creek anticline in the western corner of Bucks County is well-defined, but most of its southern limb is in Montgomery County. The anticlinal axis trends N.45°W. and plunges gently northwestward. A wide diabase dike reaches the surface about one-half mile northeast of the axis. The northeasterly dips on the northeast limb have already been mentioned in connection with the Quakertown syncline. Southwesterly dips of seven degrees occur north and south of Geryville, in the southwest limb. Farther southwest in Montgomery County, dips of 15 to 20 degrees to the southwest are common.

Major Faults

Chalfont fault

The Chalfont fault passes through the village of Chalfont in west-central Bucks County and traverses a course that is nearly due east and west, from the Montgomery County line to a point north of Wycombe, where it probably dies out. The downthrow is on the south side. Inasmuch as the character of the drag folds suggests that the displacement is eastward on the south side of the fault, considerable horizontal movement may have occurred.

The maximum throw, near Bennetts Corner southwest of Furlong, is approximately equal to the thickness of the Stockton Lithofacies plus about half the thickness of the Lockatong, an estimated 6,500 feet. The displacement decreases westward. A mile west of Chalfont it is equal to the thickness of the Lockatong, probably about 3,500 feet in that part of Bucks County. The throw is estimated as 3,000 feet at the Montgomery County line. From there westward, crushing and slickensiding define its course accurately, until it dies out about seven miles to the west.

Eastward from Bennetts Corner the large displacement is attributed to the Furlong fault which joins the Chalfont fault southwest of Furlong. The Chalfont fault there passes into Lockatong argillite, and the displacement probably does not exceed 1,000 feet at State Highway No. 263 south of Furlong.

The course of the Chalfont fault from the Montgomery County line to Bennetts Corner is sufficiently evident from the manner in which it sharply separates unlike rocks along a line that is transverse to their strike. Near Line Lexington it divides Lockatong argillite on the north from Brunswick red shale on the south. From Chalfont to Bennetts Corner the fault separates Stockton on the north from Lockatong on the south, truncating the entire thickness of the Stockton Lithofacies in a distance of seven miles.

At many places along the fault intense disturbance of the rocks can be observed. Inasmuch as Stockton sediments are poorly exposed, this is usually seen only in Lockatong argillite. Wherever Lockatong rocks can be seen near the south border of the Chalfont fault they are contorted, slickensided, crushed, or cut by minor faults. Many diverse dips show the effect of drag for distances of more than one-half mile from the fault. South of Chalfont a well-developed local syncline is produced by the drag. In the railroad cut east of the Chalfont station and at other places nearby, the rocks dip steeply southwestward and are metamorphosed to a brittle hornfels. Similar local metamorphism is visible in several exposures where Neshaminy Creek crosses the Chalfont fault. West of Chalfont on the north side of the Chalfont fault a small area of Lockatong argillite is separated from the main area of that rock by a narrow band of Stockton sandstone. Outcrops of Lockatong argillite in a ravine three-fourths of a mile west of Chalfont and in the bed of Neshaminy Creek near there dip southwestward. The small patch of Lockatong argillite evidently lies on the south limb of an anticlinal drag fold whose axis is occupied by Stockton sandstone. A southwest dip in Stockton sandstone near the axis of the same anticline was noted in the bed of the North Branch of Neshaminy Creek directly north of Chalfont. Drag folding is developed on a still greater scale north and northwest of Line Lexington, where the strike of the interbedded gray and red argillites begins to deviate from the normal homocline as much as a mile from the Chalfont fault.

East of Bennetts Corner the course of the Chalfont fault is not as clear. Local southward dips near Mill Creek 1¼ miles east of Forrest Grove and steep eastward dips and local shearing northwest of Wycombe are attributed to the Chalfont fault. The last evidence of its course appears as float of a quartzose breccia in a field one-fourth of a mile northeast of the Wycombe railroad station. Exposures are lacking for a mile east of there, and it is believed that the fault dies out in less than that distance. Where field evidence is obscure, the study of aerial photographs in stereoscopic pairs indicated the trend of the Chalfont fault. It does not appear likely that it joins the Buckmanville fault which is mapped a mile to the north, and which dies out westward. The throw of both faults in this vicinity is quite small.

Furlong fault

From Bennetts Corner northeastward to the Delaware River a mile southeast of Center Bridge, the Furlong fault brings Paleozoic and Pre-Cambrian rocks to the surface in the midst of the Triassic. In New Jersey its continuation is designated the Brookville-Flemington fault.

The downthrow is on the southeast side. The throw at Furlong is slightly greater than the thickness of Stockton and Lockatong Lithofacies, probably about 7,500 feet. Near the Delaware River, at the point where the Holmquist School fault branches from it, the throw is equal to the sum of Stockton, and Lockatong Lithofacies, and about 4,000 feet of Brunswick, probably a total of at least 10,000 feet.

Along the southwestern part of its course the Furlong fault truncates the northward-dipping Brunswick shale lying to the southeast. Due to drag folding local southerly dips occur near the Furlong fault. One such dip shows along the road between Mill Creek and the New Hope Branch of the Reading Railroad half a mile south-southeast of Buckingham Valley station. East of the station, along the south foot of Buckingham Mountain, some years ago many blocks of quartzose breccia could be seen along the roadside. They have since been almost completely removed. At the southeast foot of the mountain where a road crosses the ridge, milky vein quartz is slickensided.

Farther to the northeast, at distances of more than half a mile, Brunswick shales east of the fault typically dip towards the fault, but near the fault local southeasterly dips occur. This effect is well displayed about half a mile north of U. S. Route No. 202, two miles west of New Hope. The location of the fault is especially well-defined from Lahaska station northeastward where Paleozoic limestone adjoins red shale. In a small quarry near the fault, two miles east of Center Hill, brecciated limestone was noted a number of years ago. Northeast of this place the fault separates the limestone from a small area of Lockatong argillite. On the New Jersey side of the Delaware River, the fault passes along a small ravine, separating Stockton arkose on the northwest from crushed and contorted Lockatong argillite on the southeast.

Holmquist School fault

The Holmquist School fault branches from the Furlong fault about three-fourths of a mile west of the Delaware River. Its strike is a little north of due east, as it crosses the river and bends northward in New Jersey, where it has been designated as the Dilts Corner fault. In Bucks County it separates Lockatong argillite on the north from Brunswick red shale on the south. This portion of Lockatong Lithofacies is part of a larger area that is bounded by the extension of the Furlong and Holmquist School faults in New Jersey. The downthrow is on the south side and must be at least equal to the thickness of Brunswick shale south of the fault, that is, approximately 3,500 feet. Evidence of the Holmquist School fault in Bucks County is chiefly the areal distribution of the rocks. However, a small amount of breccia was found in the fields along its course one-fourth of a mile northwest of Holmquist School. In New Jersey the fault is plainly shown, by both the truncation and local crushing of the Brunswick shales.

Bridge Valley fault

The Bridge Valley fault passes east to west along Neshaminy Creek at Bridge Valley 3½ miles southeast of Doylestown. Evidence of it can be seen at several places for two miles in either direction. It is particularly noteworthy because, unlike most of the faults that cut the Triassic rocks in Bucks County, it has the downthrow on the north side. The throw a mile west of Bridge Valley is estimated to be more than 500, and possibly as great as 1,000 feet. For more than a mile east of U. S. Route No. 611 south of Edison, the fault separates Lockatong argillite on the north from Stockton red sandstone on the south. The strike of both rocks is nearly perpendicular to the course of the fault. Along Neshaminy Creek for several hundred yards west of Bridge Valley Lockatong argillite is intensely contorted and crushed, and the bedding, where it can be discerned, dips steeply northward. Small faults are visible in a quarry north of the Neshaminy Creek and east of State Highway No. 263, and faulting and slickensiding occur in a ravine one-fourth of a mile farther east. Crushing and slickensiding were noted in ravines one-fourth of a mile and half a mile southwest of Mozart. Further eastward extension of the fault is problematical. Local, steep dips along Mill Creek south of Wycombe are closely in line with the strike of the fault, and one minor shear zone was noted about 600 yards south-southwest of Wycombe.

West of Bridge Valley, where the fault crosses U. S. Route No. 611 south of Edison, a faulted zone was formerly visible when the road cut was new, but the exposure has since been grown over by vegetation. At the south end of a large meander of Neshaminy Creek about a half mile west of U. S. Route No. 611, faulting and shearing are conspicuous (Fig. 18, p. 136).

Buckmanville fault

The Buckmanville fault is the Pennsylvania extension of the Hopewell fault in New Jersey. The latter brings Stockton sandstones to the surface about four miles east of the Delaware River and causes the repetition of the Lockatong argillite and a large fraction of the Brunswick. The downthrow is on the southeast side. In Bucks County the fault passes between Bowman Hill and Jericho Mountain, curves southwestward through Buckmanville and past the west end of the Jericho Mountain diabase sheet. From there it trends due west, passes north of Pineville and dies out about a mile farther west.

In New Jersey close to the Delaware River the course of the fault is marked by crushing and contortion of the bedding. In Bucks County the evidence is less obvious, but shearing and intense jointing are noticeable at several places. Examples occur in outcrops in the brooks east and south of Buckmanville and about half a mile west of the saddle between Bowman Hill and Jericho Mountain. Breccia and large chunks of barite occur in the road cut on State Highway No. 232 a mile southwest of Buckmanville (Chapter VI, p. 210). West of that road the effect of the fault is evident from the discordance of strike of the rocks north and south of it. The beds to the south of the fault strike due east to several degrees south of east; those north of it strike slightly east of north. In the bank of the creek three-eighths mile west of State Highway No. 232 and directly in line with the east-west ridge of Jericho Mountain, brecciated red shale is exposed. The fault does not cut off the diabase; the sill comes to an end east of the brook. Where a farm lane crosses the brook about one-half mile farther southwest, red shale outcrops are sheared. North of Pineville and three-fourths of a mile west of there, local southwesterly dips are believed to indicate the westward course of the fault which dies out a little more than a mile west of Pineville.

The throw reaches a maximum near Hopewell, New Jersey, where it is about 10,000 feet, with downthrow on the southeast. At the Delaware River the throw is probably less than 4,000 feet, and at the brook west of Jericho Mountain it is estimated to be less than 1,500 feet.

Pidcock Creek fault

Pidcock Creek fault is an extension into Pennsylvania that branches from the Buckmanville (Hopewell) fault about 1½ miles east of the Delaware River. Its course in New Jersey is marked by severe crushing and slickensiding. In Bucks County it separates the westward-dipping rocks at the north foot of Bowman Hill from the northwesterly dipping beds farther north along the Delaware River. Downthrow is on the south side. Exposures on the river road (State Highway No. 32) where this fault crosses it show highly diverse, steep dips and slickensiding. Crushing is evident in outcrops along State Highway No. 232 north of Buckmanville. The fault dies out less than three miles west of the Delaware River. The throw is probably about 2,000 feet at the Delaware River and decreases rapidly westward. The mass of rock between the Pidcock fault and the Buckmanville fault less than a mile to the south apparently is a huge splinter partially sheared off the large block to the north.

Danborough fault

Danborough fault near Danborough three miles north of Doylestown offsets the southeastward-facing escarpment and the Stockton-Lockatong contact approximately three-eighths of a mile. The fault makes a small angle with the strike of the bedding. The downthrow is on the southeast, and the displacement is approximately 400 feet. The fault surface is not exposed, but there is ample evidence of movement. Northeast of Carversville four small faults (not shown on the geologic map of Bucks County, Plate 2, in pocket) were noted within a distance of 250 yards along the road at the foot of the escarpment. To the southwest at New Galena a mineralized friction breccia is evident from abundant float and fragments on abandoned mine dumps (Chapter VI, p. 215). From there southwestward the fault follows closely North Branch of Neshaminy Creek. An exposure a mile southwest of New Galena has closely spaced strike joints. Two miles southwest of New Galena, near the road bridge, strata of Lockatong argillite are strongly flexed, have abnormal dips, and are closely jointed parallel to the strike. The fault may die out farther to the southwest; there is no clear evidence that it joins the Chalfont fault. On the other hand, the lower part of the Lockatong Lithofacies appears thicker here, and this suggests repetition of part of the series. Northeast of Carversville the fault probably dies out in a short distance, though some shearing in a ravine on the New Jersey bank north of Lumberville may indicate its extension.

Minor Faults*

Yardley fault

In a cut of the Reading Railroad southwest of Yardley a fault of unknown throw is exposed. It strikes N.12°W. and dips steeply northeastward. Arkose and conglomerate are on the east and red shale on the west, but farther to the southwest along the railroad, arkose and conglomerate come up under the red shale. The direction of displacement is uncertain. Indications of drag suggest downthrow on the west, but the eastward dip of the fault surface is slightly favorable to downthrow on the east. If the downthrow is on the east, the displacement might be no more than 40 feet; if downthrow is on the west, the throw must exceed 100 feet.

Neshaminy Farms fault

The Stockton-Lockatong contact is offset by a fault at the southern limit of the large meander of Neshaminy Creek two miles south of Penns Park (Plate 2, in pocket and Figure 16, p. 134). Fault breccia

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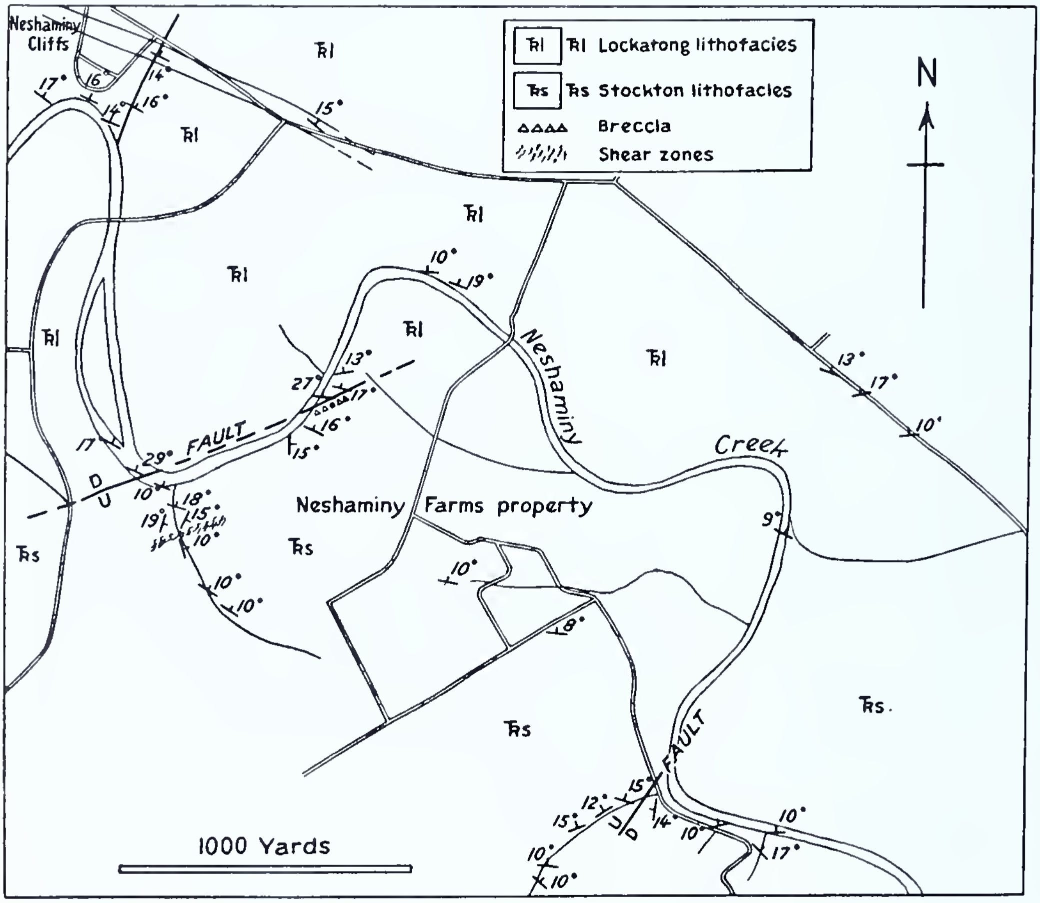
* Generally these minor faults are not shown on the geologic map of Bucks County (Plate 2, in pocket) and the sketch map illustrating principal structures of the Triassic in Northern and Central Bucks County (Fig. 15, p. 127).

Figure 16



Sketch map of vicinity of Neshaminy Farms depicting local structures.

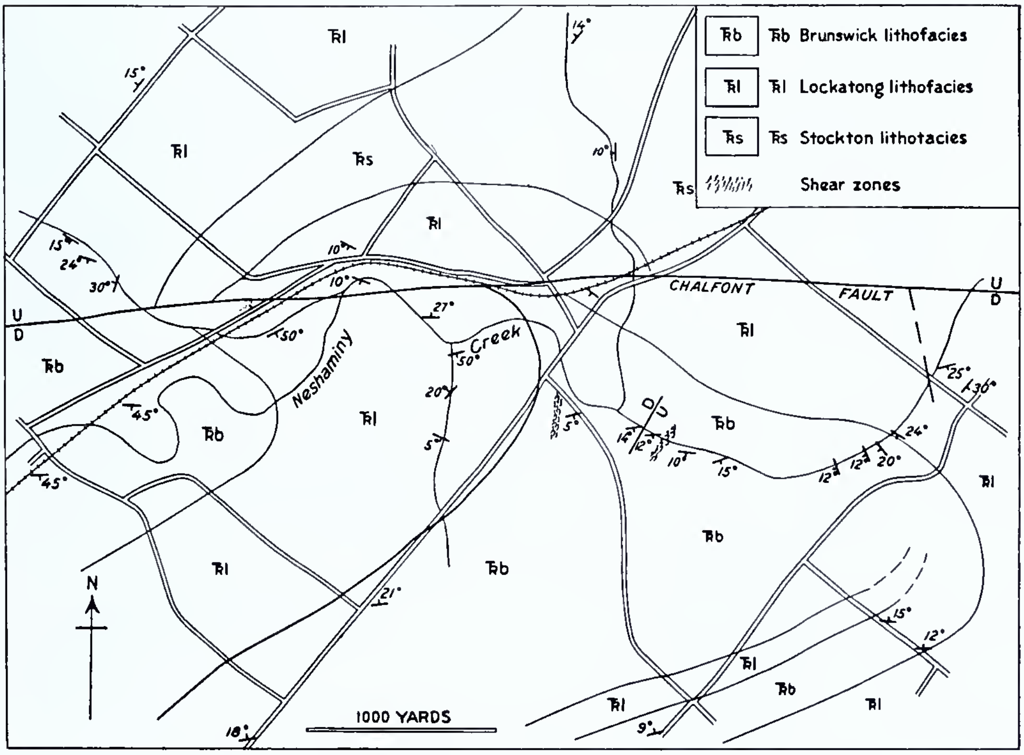
and slickensided rock are exposed in several ravines on the southeast bank of Neshaminy Creek. The fault strikes N.70° E. and dips steeply northwest. Downthrow is on the northwest side. The amount of offset of the contact requires a vertical throw of 350 feet. Lockatong argillite on the northwest is brought against upper red sandstone of the Stockton lithofacies on the southeast. Local abnormal dips affect both rocks.

An obscure fault occurs in a tributary of Neshaminy Creek about 1½ miles southeast of the fault just described. Its strike is approximately northeast and its dip only 30 degrees southeast.

Bridge Valley-Chalfont fault zone

Many minor faults are closely associated with the major faults. One of the minor faults is visible in a quarry east of the junction of State Highway No. 152 with U. S. Route No. 202 south of Chalfont (Fig. 17, p. 135). The quarry rock is Brunswick red shale overlain by black shale, and the west wall of the quarry is occupied by a mass of breccia that strikes north and dips steeply eastward. The direction and amount of throw are undetermined. A few hundred yards east of the quarry, a small fault is exposed in the bank of Neshaminy Creek. The attitude of this fault is N.35° E., 70° NW. with downthrow about 10 feet on the west. A north-south fault probably crosses Neshaminy Creek close to the road bridge a mile east of Chalfont. Black Lockatong argillite east of the bridge and along the road south of it is some-

Figure 17



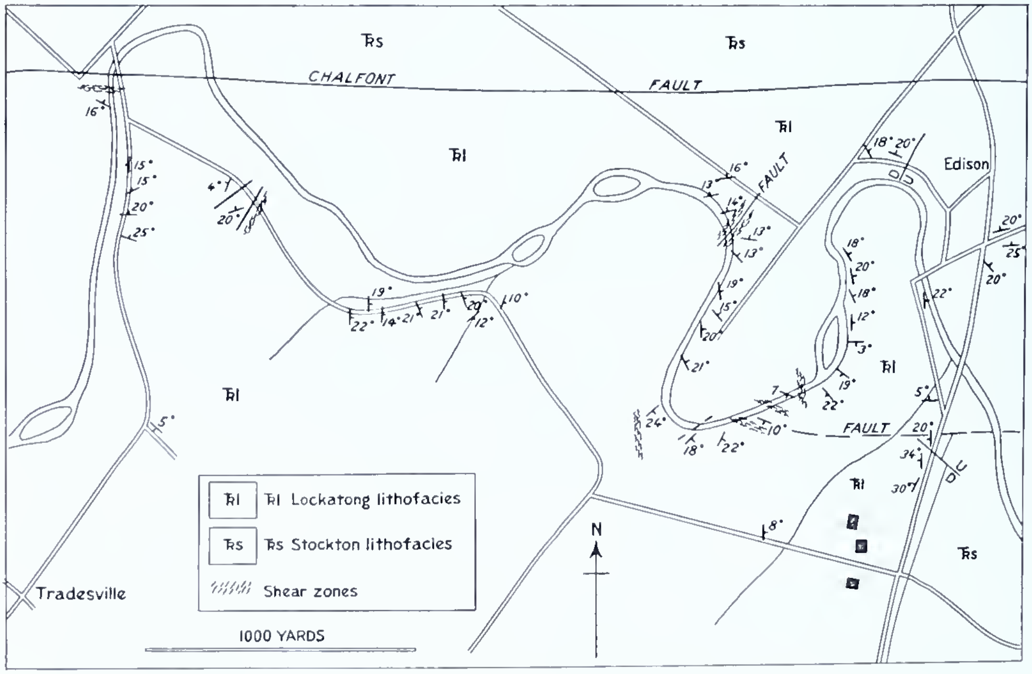
Sketch map of Chalfont area showing local structural details.

what sheared and contorted and dips southeastward. Red and black argillite a few hundred yards west of the bridge dip southwest and west with no indication of shearing.

A mile northeast of Tradesville (Fig. 18, p. 136) a quarry south of Neshaminy Creek exposes reddish-brown and gray, fine, sandy argillite cut by at least two faults that strike northeasterly. Much of the rock is severely contorted and sheared, but where bedding is discernible it dips 20°NW. About one mile due east of the quarry a fault is exposed east of the northernmost point of a large bend of the creek. The fault surface strikes N.35°E., and the downthrow is probably on the east. It separates northwesterly dipping gray argillite from a series of outcrops that dip eastward. East of the southern limit of the next bend (about half a mile west of U. S. Route No. 611) there are several shear zones, most of which strike north-south, but a few, east-west. The latter are believed to be related to the Bridge Valley fault. Extremely diverse dips occur within a few hundreds of yards, partly due to flexures rather than to faults. At the eastern end of the large quarry at Edison (Fig. 18, p. 136), a fault surface strikes due north and dips 35°W.

A fault is exposed about one-quarter mile south of the mouth of the brook that flows into Neshaminy Creek half a mile west of Bridge Valley. The fault strikes northeastward, and the downthrow is on the northwest side. It brings Lockatong gray argillite against thick-bedded, Stockton gray arkose. The throw is certainly less than 150 feet and may be no more than 50 feet. A few hundred yards south of this fault, Lockatong argillite again appears in the bed of the brook, probably overlying the Stockton arkose conformably.

Figure 18



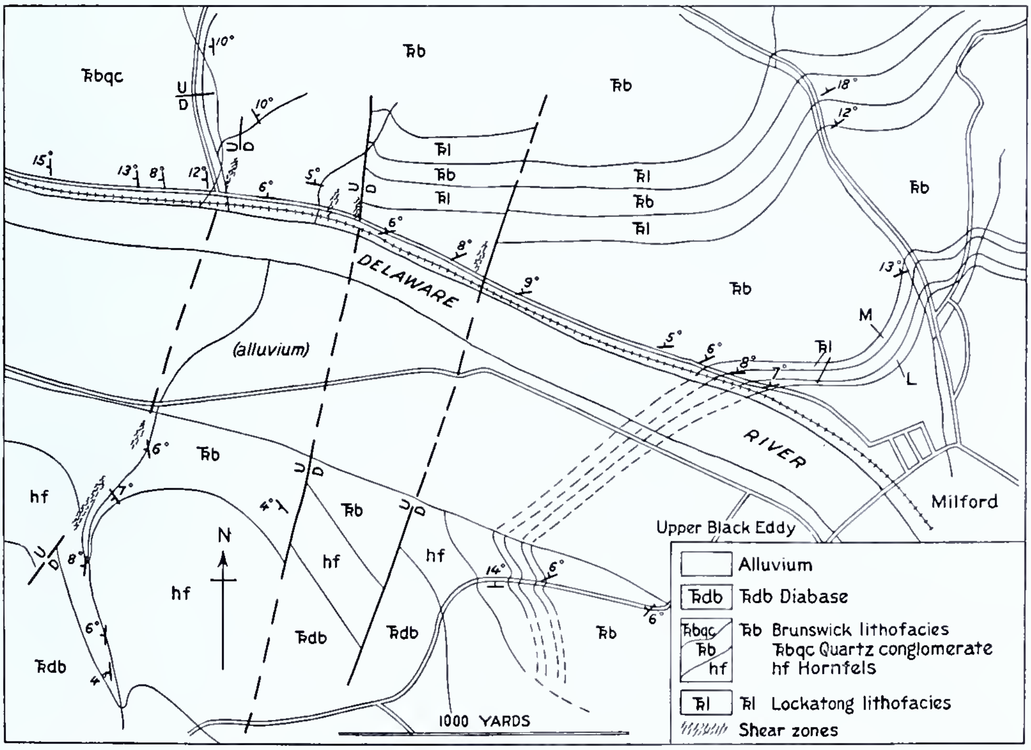
Sketch map of area northeast of Tradesville to Edison depicting structural peculiarities.

Upper Black Eddy faulted area

Along the northern edge of the Coffman Hill area (Plate 2, in pocket) of diabase the boundaries of diabase, hornfels and red shale are offset by several faults (Fig. 19, p. 137). The easternmost is about three-fourths of a mile west of Upper Black Eddy. It is not exposed in Pennsylvania, but it causes a marked irregularity of the boundaries. It is excellently displayed in a ravine in the bluff on the New Jersey side of the Delaware River, where it causes visible displacement of thick sandstone beds and is easily seen from the Pennsylvania shore. The throw is approximately 60 feet downward on the east.

The next fault is about 300 yards farther west. On the Pennsylvania side it occupies a steep ravine in the bluff, along which hornfels on the east adjoins Brunswick red shale on the west. The fault surface is not visible. On the New Jersey side, the fault is exposed beside the river road, and from the offset of a gray shale bed its down-throw to the east is estimated as 200 feet.

FIGURE 19

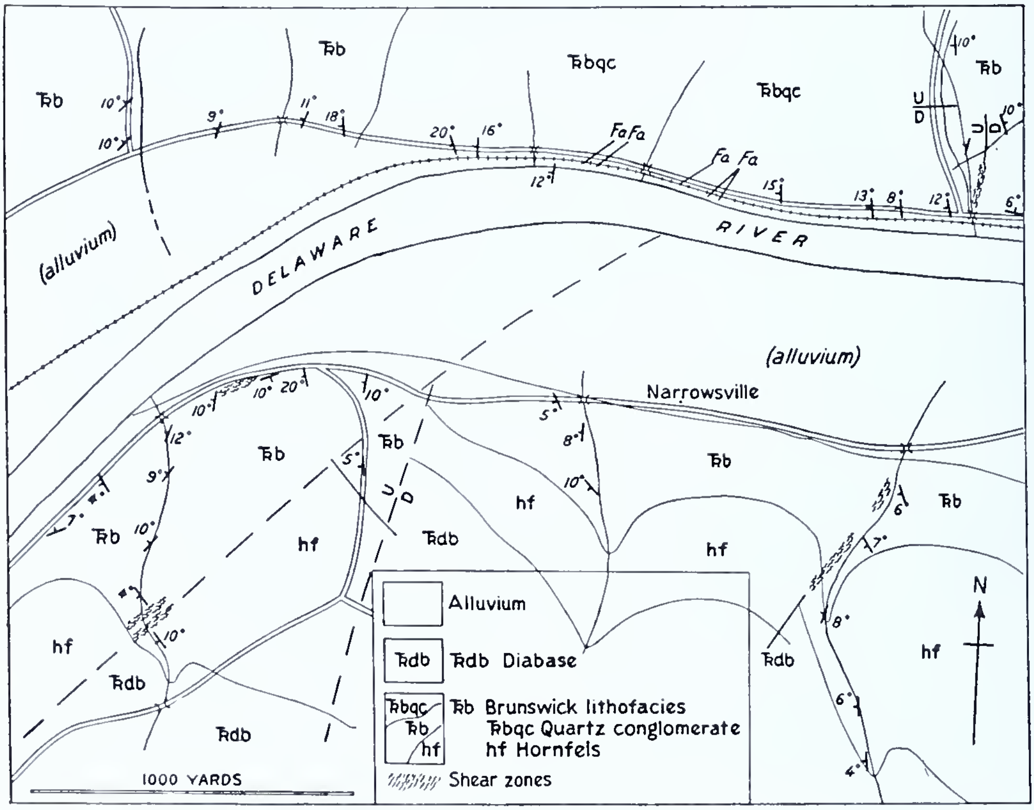


Sketch map of Delaware Valley northwest of Upper Black Eddy showing local faulting along border of Coffman Hill sheet.

The third fault, about half a mile farther west, is less conspicuous. Near the foot of the ravine that heads at Ringing Rocks, a red shale exposure is somewhat sheared. One-quarter of a mile south of the river road and high on the west bank of the ravine, hornfels is strongly sheared, and the cleavage dips steeply southeastward. This locality is directly on the strike of a fault in a ravine on the New Jersey side of the Delaware River, where the displacement may exceed 200 feet. There the fault separates northward dipping red shale and sandstone on the east from westward dipping conglomerate and shale on the west. Downthrow is on the east side and must decrease southward, so that the throw is rather small in Pennsylvania, and the fault probably dies out near the Ringing Rocks.

A mile farther west, at Narrowsville, two faults are required to account for the distribution of diabase, hornfels and red shale (Fig. 20, p. 138). A few hundred yards east of the road that climbs the bluff at Narrowsville, the hornfels comes down the bluff nearly to the river road (State Highway No. 32). Immediately, it is succeeded to the west by red shale that dips westward to northwestward away from the hornfels. Red shale occurs for about 400 yards southward along the road up the bluff. It dips away from the hornfels and the overlying diabase east of the road. A fault with strike approximately N.20°E. is required to explain these relations. Downthrow is on the east and is estimated as 250 feet.

Figure 20



Sketch map of Delaware Valley at Narrowsville showing local structural details.

In the deep ravine on the line between Bridgeton and Nockamixon Townships, sheared exposures occur several hundred yards south of State Highway No. 32. North of the shear zones, the red shale in outcrops in the ravine dip northwestward away from the sheared exposures and away from a boundary between red shale and hornfels that extends from the sheared outcrops northeastward across the fields. The boundary is interpreted as the trace of a fault zone with downthrow of about 250 feet on the southeast. Continued northeastward, the strike of this fault intersects the Pebble Bluffs in New Jersey. There, along the river road, at least five faults have been noted within a distance of one-fourth of a mile. According to computations (Fig. 13, p. 101), the total throw of these faults on the New Jersey shore may exceed 800 feet. However, the apparent amount of displacement may be exaggerated by local thickening of the beds due to the fanglomerate in the upthrown block.

Kintnersville faulted region

The western fault at Narrowsville probably determines a part of the boundary between diabase and hornfels northwest of Coffman Hill. Its strike intersects a deep ravine about three-fourths of a mile southeast of Kintnersville, where the rocks are strongly sheared. Half a mile farther southwest the fault zone crosses U. S. Route No. 611 south of a deep ravine. In the lower portion of the ravine there is sheared red shale. Two gray shale beds that are exposed to the south are cut off by the fault north of the ravine. Along the highway to the south the large exposures contain six faults within about 100 yards. All of them dip southeastward about 50 degrees. The aggregate throw is probably less than 100 feet, since the contact of red shale with overlying hornfels is displaced no more than that amount. One-fourth of a mile west of U. S. Route 611 and directly on the strike of the fault zone, a large exposure on the south bank of Gallows Run shows diverse dips, slickensides, and a probable fault.

One-quarter of a mile northwest of the fault zone just described on Route No. 611, another fault parallel to it intersects the ravine southeast of Kintnersville, where intense shearing and probable displacement of undetermined amount occur. On the steep bluff east of U. S. Route No. 611 a gray shale bed in the red shale can be traced diagonally upward to the south until it ends abruptly and is followed by sheared fragments of red shale. The gray bed was not located south of the fault, but inasmuch as the contact of red shale and hornfels is not greatly displaced, the throw probably does not exceed 60 feet. The strike of this fault, continued to the northeast, should intersect the steep cliff that faces the Delaware River. A careful search failed to reveal any dislocation there, although a few slickensided fragments of shale were found, and closely spaced joints were noted a few hundred yards west of the deep ravine at the east end of the cliff.

Along State Highway No. 32 for 200 yards east of its junction with U. S. Route No. 611 at Kintnersville, red shale in outcrops has extremely variable dips up to 35° to the southeast, southwest, and northwest. An obscure fault may pass near the road junction, but no other indication of it was found.

Shearing was noted at a few other places near Kintnersville, but at none of these was there evidence of appreciable dislocation. One such exposure is 0.2 miles southeast of U. S. Route No. 611 along the ravine southeast of Kintnersville. Others are at the road corner at the mouth of that ravine, and along U. S. Route No. 611 about 200 yards and 750 yards north of the junction with State Highway No. 32. The latter zone was found at two other places within 700 yards to the west along a ravine that heads near Chestnut Hill. One-fourth of a mile west of U. S. Route No. 611, on the east-west road half a mile south of Kintnersville, an outcrop of red and blue shale is sheared and contorted.

About 500 yards north of Ferndale on U. S. Route No. 611, a vertical fault with northeasterly strike brings thick-bedded, sandy argillite on the southeast against thin-bedded, red shale on the northwest. The displacement must be small, for there is no considerable offset of gray shale beds nearby.

Evidence of faulting at the north border

At several places along the north border of the Triassic area the rocks are somewhat sheared or visibly faulted, but these are not as numerous, nor are the disturbances as intense, as would be expected if a profound post-Triassic fault determined the border. That some post-depositional faulting or tilting has taken place is shown by the moderately steep dip of Triassic beds towards the border at some places. This is especially conspicuous in New Jersey several miles east of the Delaware River.

A few yards west of the river road (U. S. Route No. 611) at Monroe, an outcrop of limestone is schistose, but other parts of the same exposure are not. In the next half mile to the southwest, the bed of the brook contains numerous exposures of gneiss, none of which exhibits shearing, though Triassic fanglomerate occurs within a few yards. At the road corner 2½ miles southwest of Monroe, an exposure of limestone conglomerate and red shale is slickensided. In the bed of the brook half a mile to three-fourths of a mile west of Franklin School there are two small faults and two minor shear zones, yet a long succession of good exposures appears remarkably undisturbed. The close juxtaposition of Paleozoic limestone and Triassic limestone conglomerate at this locality indicates that it is unlikely that a large displacement has occurred since the deposition of the conglomerate. Rather extensive shearing and contortion affects red shale outcrops along the road west of Durham (Cook) Creek 1½ miles north-northeast of Pleasant Valley.

In New Jersey several miles east of the Delaware River the north border is determined in part by an important fault. East of Pattenburg (Figure 14) the Triassic overlaps a floor of Paleozoic limestone that is exposed in an area of several square miles. The Paleozoic limestone in turn is faulted down against the gneiss ridge north of it. The strike of this fault lies along the north border of the Triassic from Pattenburg southwestward past Monroe, to the vicinity of Franklin School. West of there the fanglomerate of Flint Hill extends north of the continuation of that line.

On the whole, the evidence points to local, minor post-Newark Group faulting in the border zone. The faulted regions near Kintnersville and Upper Black Eddy are probably part of this system of minor faults. Perhaps there is a fault with a throw of a few thousand feet between the gneiss ridge and the pre-Triassic floor east of Monroe, and it may extend several miles into Pennsylvania. But it is suggested that this fault was formed during the deposition of the Newark Group. There is not much evidence of large movement along it after the end of sedimentation. The rocks next to the border are much less disturbed than those near the Chalfont fault, for example.

Further discussion of this question is given in the section on Stratigraphic Relations of the Brunswick Lithofacies (Chapter IV, p. 106).

Steep dips near Wycombe

The steep dips of Brunswick red shales at Wycombe and of the Lockatong and Brunswick Lithofacies south of there in the section along Mill Creek and the railroad require special comment because it has not been demonstrated that important faulting affects that section. The steepest local dip, 45 degrees, was observed at a red shale outcrop at the west end of the road bridge at Wycombe. Although the section was thoroughly examined, no indications of extensive faulting were found. One minor, shear zone was noted 600 yards south of Wycombe, in the bank of Mill Creek. The section farther south shows numerous alternations of red and gray shale (Table 20, p. 86), but enough contacts were found to warrant the conclusion that the alternations are due chiefly to interfingering rather than to faulting. The steep dips are simply the culmination of a gradual increase of steepness that occurs throughout the section from Rushland northward to Wycombe.

The structure is probably related to the Bridge Valley fault which affects the region a few miles to the west. The downthrow is on the north side and, as the fault dies out eastward, it passes into a strong flexure that is expressed by the steepening of dip. The structure may also be due in part to a marked local thickening of the series in the area about Penns Park. Thus, a dip impressed by local subsidence during deposition would be added to the dip caused by later tilting of the major fault blocks.

TRIASSIC IGNEOUS AND CONTACT METAMORPHIC ROCKS

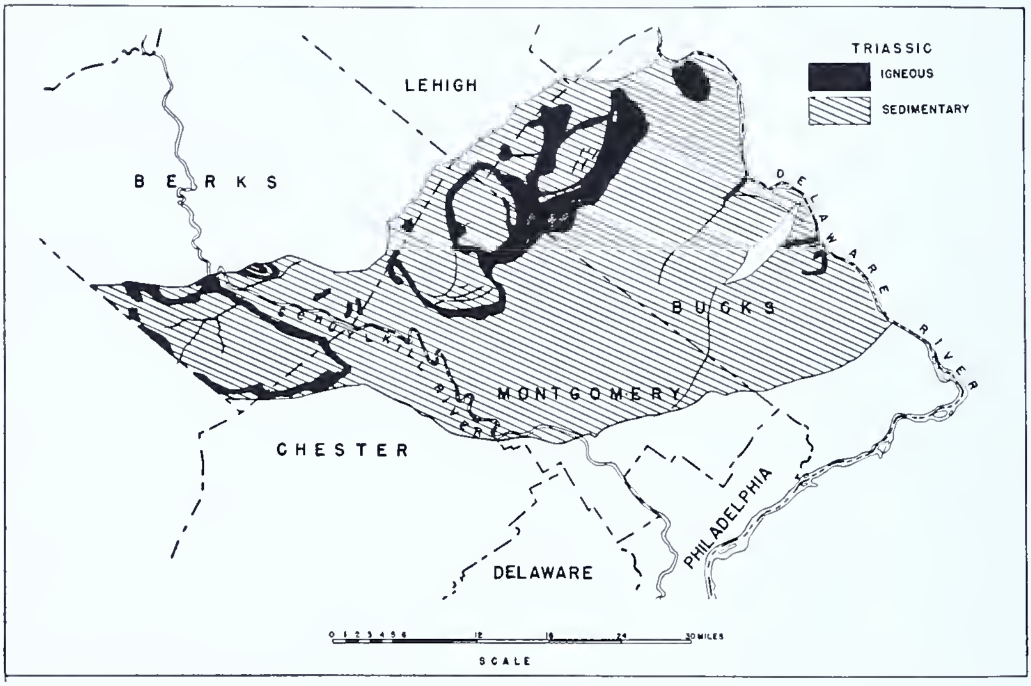
by

D. B. MCLAUGHLIN, J. DONALD RYAN AND BRADFORD WILLARD

Introduction

Basic hypabyssal and extrusive rocks in the Triassic basins of eastern United States have long been the subject of considerable interest; many of the larger bodies have been cited again and again in petrologic literature. Typical of these rocks are the hypabyssal, basic intrusive bodies of Bucks County. These rocks consist almost exclusively of diabase sheets and dikes which have intruded and locally metamorphosed the clastic rocks of the Newark Group. In a number of these sheets, small occurrences of syenite are locally observed to grade into diabase. No extrusive rocks crop out in Bucks County. The distribution and structure of the igneous and metamorphic rocks are shown on the geological map of Bucks County (Plate 2, in pocket and Fig. 21, p. 142). Normally, the presence of igneous rocks is easily predicted in the field, inasmuch as the relatively resistant diabase and hornfels bodies form ridges or high prominences. However, resistant layers of Lockatong argillite or of Stockton conglomerate may form similar prominences.

Figure 21



Distribution of igneous rocks in Bucks, Montgomery and Berks Counties.

Jericho Mountain

The outcrop of the diabase on Jericho Mountain (Plate 21B, p. 145) is not strictly conformable to the strike of the shales southeast of the mountain, nevertheless the intrusion is interpreted as a sill that cuts across the strata locally. The western half lies 400 to 500 feet lower in the shale series than the eastern half. The diabase cuts across the bedding between one-fourth of a mile and half a mile west of the road that crosses the mountain north of Woodhill. At the western end the sill terminates a few hundred yards west of State Highway No. 532, and is not cut off by the Buckmanville fault.

Bowman Hill

Along Pidcock Creek at the north foot of Bowman Hill the metamorphosed shale dips 30°W. It is exposed in some places only a few yards from the fine-grained contact phase of the diabase which rises steeply on the south bank of the stream. Pidcock Creek has eroded its channel almost along the contact for more than half a mile. The intrusion is evidently a large dike that cuts perpendicularly across the strata. Probably it was a feeder of some of the large sills, notably that of Solebury Mountain.

Solebury Mountain

At the Delaware River the Solebury Mountain intrusion is continuous with a large sill in New Jersey that is conformable with the shale bedding for several miles northeast of the Delaware River. Its thickness is 800 to 900 feet. About a mile west of the Delaware River it narrows, and its southwesterly course changes to due west. Abundant exposures of Brunswick red shale both north and south of the diabase dip 15 to 30 degrees northwestward. The sill evidently passes westward into a dike that ascends in the series to the west. Inasmuch as there is little or no hornfels between diabase and red shale, the western part of the north border of the diabase for a mile or so is probably a tear fault that branches from the Furlong fault. The intrusion is not cut off by the Furlong fault, but ends east of it.

Point Pleasant Sheet

The intrusion at Point Pleasant is part of a body of diabase that crops out in a wider area in New Jersey. The diabase clearly continues across the Delaware River, where it forms rapids, and joins the exposures on the New Jersey side. On the Pennsylvania shore no contacts are exposed, but the approximate base of the sheet is easily traced up the bluff to the southward, several feet above a massive bed of metamorphosed Lockatong argillite. The sheet is at least 210 feet thick. The upper contact does not come down to road level beneath the overlying argillite; instead the diabase ends northward against argillite, with no indication of faulting. It is concluded that the northern edge of the intrusive cuts across the strata. This relationship is confirmed by an exposure of the contact at Byram, New Jersey, directly opposite Point Pleasant. There, south of the ravine and only a few yards from the railroad, the metamorphosed argillite dips 12 degrees north but the diabase argillite contact dips 40 degrees south (*cf.* Kümmel, 1897, fig. 5, p. 75), thus cutting across the bedding. North of this exposure, at a slightly higher stratigraphic level, diabase with concordant contact relations is exposed. Apparently this is an extension of the diabase sheet which is not present on the Pennsylvania side of the river.

Coffman Hill Sheet

A large diabase sheet crops out in a nearby area of roughly twelve square miles underlying Coffman Hill in the northeastern part of Bucks County. This sheet occupies a shallow structural basin which, although trendless, lies nearly perfectly on strike with the large Haycock sheet. Possibly the two sheets were once connected (Hotz, 1952).

The elliptical outline of the outcrop of the Coffman Hill sheet is nearly conformable to the strike of the surrounding shales that dip under it. On the southwest, west, and north sides, the base of the sheet is probably near the same shale horizon everywhere. Comparison of sections of the shales and the tracing of identifiable gray beds in the red shale indicate that along the east side the base of the intrusion is about

400 feet lower in the section than at other parts of the boundary. As the contact is followed eastward along the southern boundary of the diabase, it cuts downward in the section west of Erwinna, remains at the lower level northward for about 2½ miles, and rises again across the strata south of Upper Black Eddy. Table 30 (p. 146) compares the sections on the southwest, southeast and east sides of the area.

TABLE 30. *Stratigraphic sections of shales beneath Coffman Hill sheet*

Rock	*South of Revere Feet*	*West of Erwinna Feet*	*West of Uhlertown Feet*
Diabase	....	....	....
hornfels	250	280	240
red shale	215	hornfels*	hornfels*
gray shale "M"	7	hornfels*	hornfels*
red shale	50	46	hornfels*
gray shale "L'	17	15	hornfels*
red shale	300	348	180
gray shale "K"	13	10	10
Total interval from base of K to base of sheet	852	699	430

---

* This entry means that the member listed in the first column is included within the hornfels.

It is estimated that the thickness of the sheet before erosion was at least 500 feet. No roof sediments remain, but from the variation of thickness of the hornfels beneath the sheet, it is inferred that the diabase was thinnest to the northeast. There is no diabase at the same horizon directly across the Delaware River from Upper Black Eddy. Either the sheet pinched out entirely near the present course of the Delaware River, or it ascended eastward so high in the shales that its extension into New Jersey has been entirely eroded. Inasmuch as the shales north of Milford, New Jersey, appear to represent a thickness of more than 2,000 feet above the stratigraphic level at which the sheet occurs in Pennsylvania, the first interpretation seems the more probable.

Exposures are few, and at many places the presence of the sheet is inferred from numerous boulders scattered haphazardly on the land surface. At Ringing Rocks, a boulder field approximately three acres in extent (Plate 22, p. 147), composed of thousands of huge residual boulders and cobbles form a virtual sea of rock or felsenmeer (Fackenthal, 1919). When struck sharply with a hammer, the rocks emit a distinct ringing sound. Wherry (1912a) attributes this to the diabasic texture of the rock and the resulting close network of minerals in which sound waves may readily develop.

Haycock Sheet

The base of the great intrusion at Haycock Mountain (Plate 21, A, p. 145) is about 800 feet higher in the Brunswick shale series than the base of the Coffman Hill sheet east of Revere. This relationship is shown in the structural contour map, Figure 13 (p. 101) and the structure sections that accompany it. It is also evident from the thicknesses between the gray shale "K" and the diabase, in Table 31 (p. 146).

PLATE 21

A. Haycock Mountain, viewed from the south.

B. Eastern end of Jericho Mountain, viewed from tower on Bowman Hill.

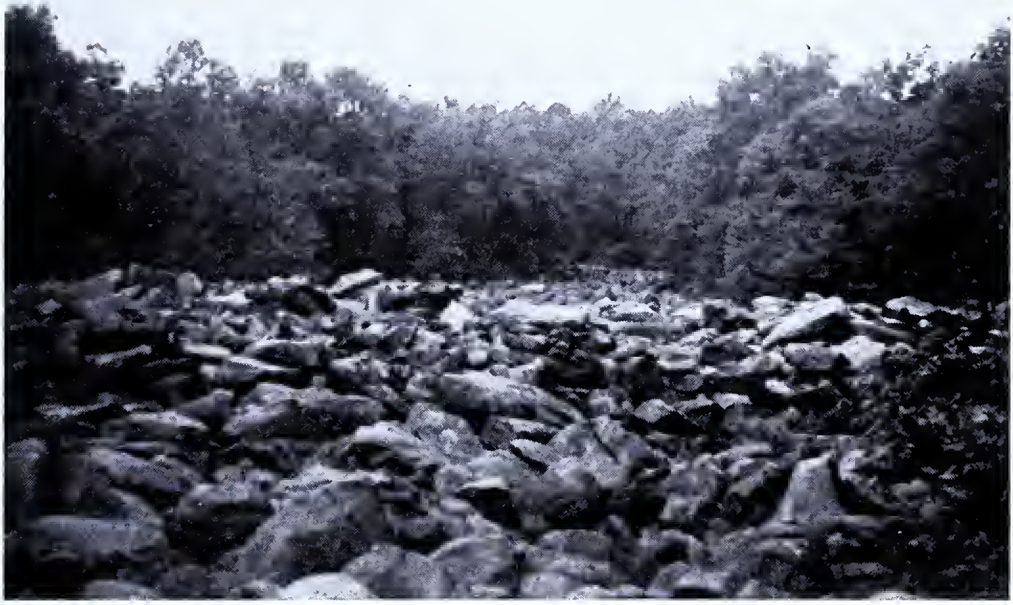
TABLE 31. *Stratigraphic sections from shale "K" to bases of Coffman Hill and Haycock Mountain sheets*

	South of Revere Feet	*Tinicum Creek Feet*	*Tohickon Creek Feet*	*Perkasie Feet*
Diabase	Coffman		Haycock	Haycock
Hornfels and gray to reddish argillite	250		650	825
Red shale	(hornfels)		180	140
Gray argillite (Perkasie member)	(hornfels)	200	144	380
Red shale	215	215	250	
Gray shale "M"	7	10	11	
Red shale	50	50	17	610
Gray shale "L"	17	15	4	
Red shale	300	300	>140	
Gray shale "K"	13	15		17
Total	852	805	>1,396	1,972

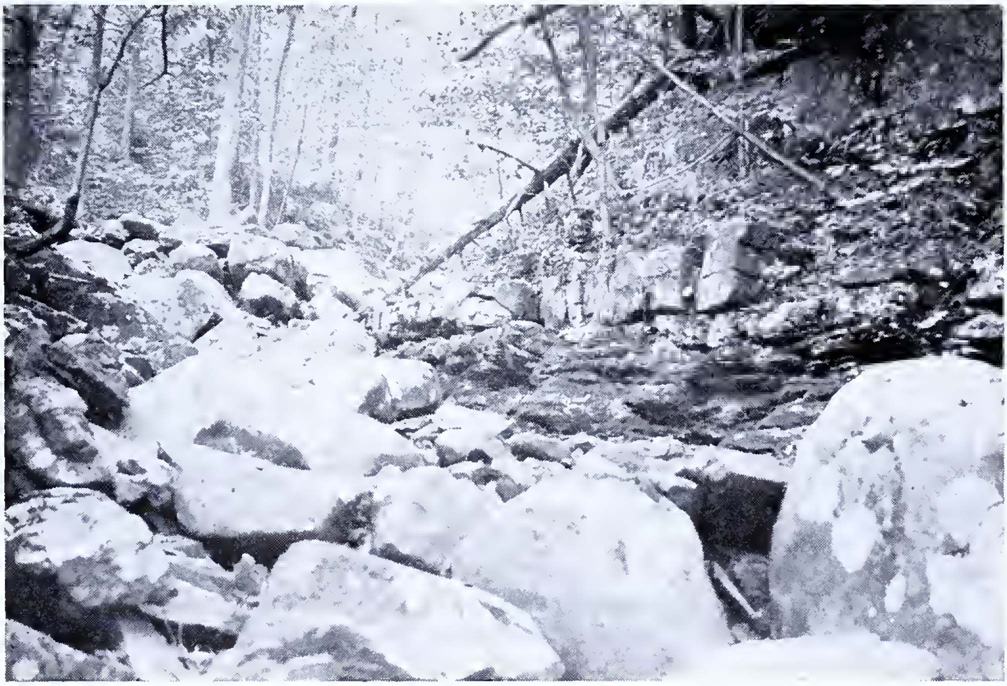
All the way from a point southwest of Gallows Hill to northwest of Sellersville, the base of the Haycock intrusive lies close to the same shale horizon. Its curving outline at the east foot of Haycock Mountain is the expression of a westward-plunging syncline. Near Altmont the basal contact descends in the Brunswick Lithofacies about 400 feet and continues westward at that lower horizon to the Montgomery County line. Where the Reading Railroad crosses the sheet south of Quakertown, the thickness of the diabase is computed to be about 1,700 feet. Hersey, (1944, p. 439) found a gravitational high over the Triassic sedimentary rocks at Quakertown and stated that "the gravity anomaly could be caused by an intrusive roughly 100 feet thick near its edges and about 1800 feet thick along its axis." The upper contact, so far as can be determined, is conformable to the bedding of the overlying shale all the way from Applebachsville to near Trumbauersville. Near the northern end of the sheet, east of Pleasant Valley, the upper contacts cuts across the strike of the shales at an angle of nearly 30 degrees. The southerly extension of the beds thus cut off is believed to be represented by the large inclusion northeast of Applebachsville. The local steepness of the dips near Pleasant Valley, more than 25 degrees WSW., may be partly due to the intrusion. At its northern end the thinned sheet sends several apophyses into the shale and terminates nearly a mile from the north border of the Triassic area. Haycock Mountain appears to represent a local thickening of the sheet into a laccolith-like body. The plunging syncline that it occupies may owe its origin to subsidence beneath the igneous rock.

The red sediments of the Brunswick Lithofacies intruded by the great sheet have been characteristically baked and metamorphosed into hard, black hornfels. The metamorphic zone is relatively wide, particularly in places along the southeastern edge of the sheet. The dashed line in this area in Plate 2 (in pocket) represents the limit beyond which Brunswick shales (McLaughlin, p. 98) show no discernible change in color. The usual symbol for hornfels is retained for those beds in which metamorphic minerals are present (Watson, personal communication).

PLATE 22



A. Felsenmeer of diabase boulders at "Ringing Rocks," one and one-half miles west of Upper Black Eddy.



B. Red shale (Brunswick) outcrop and diabase boulders washed down from head of ravine, Ringing Rocks.

The gradation from hornfels to red shale along the strike is excellently displayed in ravines about half a mile south-southwest of Franklin School.

Each of the sedimentary areas framed by igneous rock is structurally a shallow basin. Each of the branches of diabase from the Haycock sheet's main outcrop lies along an anticlinal axis. The entire area from the southeastern limit of the Haycock sheet on the east, westward to or nearly to the Triassic border may be underlain by a single, large sheet or sill which is exposed here and there due to differentially eroded structures (Spencer, 1908 and Hotz, 1952).

In the western part of Bucks County, west of Trumbauersville, the diabase cuts northward across the shale strata and sends a wide dike northwestward into Lehigh County. This dike reaches the surface about half a mile northeast of the axis of the Hazelbach Creek anticline.

Shelly Intrusive

The Shelly intrusive body north of Quakertown is irregular, both in outcrop pattern and in its relation to the enclosing sediments. From the village of California northward, its eastern boundary is approximately parallel to the strike of the westward-dipping shales, and it may have the attitude of a sill. Southwest of California Village it cuts across the strata on the northeastern limb of the Quakertown syncline, but it then passes into a thin sheet whose outcrop trends south for nearly two miles and next bends westward, following the curving strike of the shale past the synclinal axis. This thin sheet terminates at a cross-cutting dike near Milford Square. Along its western and northern boundaries the Shelly intrusive apparently cuts irregularly across the bedding. The contact is exposed in the cut of the Reading Railroad at the Lehigh County line. The shale beds in the northern part of the cut are only slightly altered, and metamorphism increases southward. The diabase contact cuts steeply in a northeasterly direction across the shale strata which dip gently southward.

Dikes and Sheets

A large dike cuts across about 3,000 feet of Brunswick shales from the Haycock sheet north of Applebachsville to the Shelly intrusive at California. Another dike leaves the Haycock sheet southwest of Trumbauersville and cuts across the Quakertown syncline, past Milford Square, to join the Shelly intrusive near Brick Tavern. A third great dike, (p. 127) extends from the Haycock sheet west of Trumbauersville northwestward beyond the Lehigh County line.

One mile north of Spinnertown at the Lehigh County line, a small sheet of diabase extends into Bucks County from Lehigh County. This may have once been part of the Haycock sheet.

Near the Delaware River there are several dikes. A prominent one extends four and one-half miles across the strike between Carversville and New Hope. This dike also cuts the Paleozoic limestone of Buckingham Valley and terminates against the Furlong fault.

At Mount Gilboa, New Jersey, (Plate 2, in pocket) a diabase sheet about 500 feet thick is enclosed in an almond-shaped "island" of Lockatong argillite bounded by a split in the Flemington fault. The diabase sill does not crop out on the Pennsylvania side of the Delaware River, but a few diabasic boulders have been found on the triangular-shaped, fault-bounded patch of Lockatong Lithofacies north of Holmquist School.

In the west-central part of Bucks County, at least two more dikes are mapped. The more northern of the two appears north of the Chalfont fault at Chalfont and curves northeastward in an arc almost three miles long. The geologic map accompanying U. S. Geological Survey Bulletin 828 (Bascom, 1931) indicates that this dike is probably continuous with the Point Pleasant sheet. Although this correlation could not be reëstablished during the present investigation, it seems a probability. Five miles southeast of Chalfont another dike has been traced from the south side of Neshaminy Creek southward to the Montgomery County line near Warminster. According to Stose (1944), this dike is part of the so-called Conshohocken dike which extends to the Susquehanna River in Maryland.

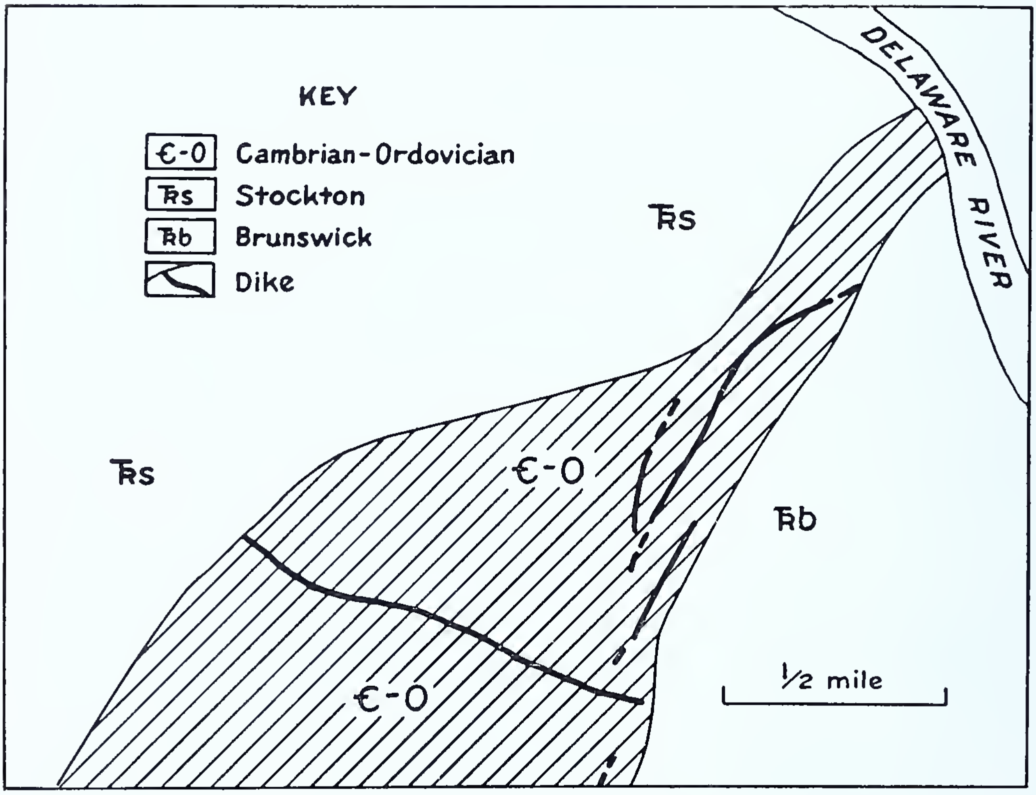
Miscellaneous Small Dikes

A number of small diabase dikes, more or less isolated from the main intrusives, have been encountered in the Triassic rocks of Bucks County. Some are intermittently exposed, others are mapped on the distribution of scattered diabase boulders or float. From one to two miles northwest of Quakertown, two small dikes trend northeastward across the strike of Brunswick red beds. Running due west from Brick Tavern a mile north of Milford Square, a dike nearly two miles long has been spotted at a few exposures and by residual boulders. What may be part of a small dike was found amidst the hornfels a mile north of California Village. A small dike runs parallel to the southern border of the Solebury Mountain intrusive for three-fourths of a mile, half a mile west of the Delaware River. Lessentine (1951) discovered a few small dikes recently exposed in the New Hope limestone quarry west of New Hope Village (Fig. 22, p. 150). This discovery was made too late to be included in the geologic map of Bucks County (Plate 2, in pocket).

There is some evidence of buried or eroded intrusions. For three-fourths of a mile south and 1½ miles southeast of Steinsburg, the surface rock is a white-weathering, metamorphosed shale of the Brunswick Lithofacies. No body of igneous rock now exposed can account for such extensive alteration. As the area lies in the axis of the Quakertown syncline, it is possible that an overlying sheet has been completely eroded. On the other hand, metamorphism may be attributable to an underlying, concealed igneous mass. The diabase at the Lehigh County line west of Steinsburg may be a remnant of the hypothetical intrusive. Alternatively, the irregular intrusion about Shelly and Zion Hill may extend underground through the Steinsburg area.

Northeast of Gallows Hill an area of greenish-gray, sandy shale extends towards Kintnersville and terminates southeast of Chestnut Hill near the center of the Ferndale dome. Towards the southeast, this rock grades rapidly along the strike into normal red shale. The boundary cuts practically at a right angle across the strata through a thick-

Figure 22



East end of Buckingham Valley between Center Bridge and New Hope showing basic dikes recently identified and not shown on the county map.

ness of about 600 feet. The discoloration affects an additional 200 feet of shale for a distance of more than a mile southeastward along the outer zone of gray argillite (the Perkasie member) northeast of Haycock Mountain. An interpretation of the discoloration as due to metamorphism by either a buried or an eroded intrusion meets with difficulties. Possibly it may be attributed to a diagenetic change, instead of to igneous action.

At the Nockamixon Township quarry a mile northwest of Ferndale, red shale grades eastward along the bedding into gray argillite that looks like the first stage of alteration to hornfels. Extensive interbedding of red and gray shale occurs in the bed of Gallows Run for one hundred yards or more east of there. About 600 yards north of Ferndale on U. S. Highway No. 611, red shale grades along the bedding into black argillite and back to red shale again within a distance of 50 yards. No diabase was found in the vicinity. A dike that terminates underground is suggested.

An area of greenish gray argillite or probable hornfels lies north of Pidcock Creek a mile west of Bowman Hill. This is tentatively interpreted as an up-faulted body of hornfels that formed near the Bowman Hill dike. It is close enough to the hornfels zone about Solebury Mountain to suggest a former connection between Bowman Hill and Solebury Mountain intrusions.

Spencer (1908) and Hotz (1952) proposed that the ring-like diabase intrusions in Pennsylvania are unbroken sheets. These could account for the observed metamorphism.

Feeders of the Sheets

Except for the dikes that cut across from the Haycock sheet to the Shelly intrusive, no feeding dikes have been found in actual contact with the underside of any of the great sheets in Bucks County or in adjacent regions. However, there is presumptive evidence that such feeders exist, but have not been exposed by erosion. At Point Pleasant sheet there is a dike that cuts the underlying shale, but it is not exposed to any considerable depth. Bowman Hill is a great dike that cuts perpendicularly across the strata, and its location suggests that it may have fed both Solebury Mountain and Jericho Mountain sheets. The accident of its isolation by faults is the cause of the impossibility of observing the connection now. Another case of possibly similar character is the diabase at Mount Gilboa on the New Jersey side of the Delaware River two miles north of New Hope. This rock, in part so coarse-textured that it has been called a gabbro, intrudes Lockatong argillite. It may have the attitude of a sill along its eastern border, but on its western side near the Delaware River it cuts vertically across the argillite strata. This igneous mass also is isolated from others by faults, yet, it may well have been the feeder of a sill now completely eroded. It is possible, too, that most of the sheets and bosses in eastern Pennsylvania and western New Jersey, now separated, were once connected (Hotz, 1952).

The most spectacular Triassic dike in eastern Pennsylvania is one that extends from Harmonyville, Chester County, northwestward to Gibraltar Hill on the Schuylkill River south of Reading. With an average width of nearly half a mile, it cuts across more than 10,000 feet of strata from the crystalline rocks of the pre-Triassic floor to a stratigraphic level high in the Brunswick Lithofacies. It is not connected with any sheet that is now exposed over any considerable distance, but its dimensions appear quite adequate to have permitted it to feed the largest of the intrusions in the Newark Group (Hotz, 1952, p. 386).

ORIGIN OF THE STRUCTURES

The origin of the basin and anticlinal structures of the sedimentary and igneous rocks is not clear. Except for the border fault, the only displacements are a few normal faults. No thrust faulting is recognized, nor is there indication of compressional folding. The pattern of the folds as shown is not that which would be produced by orogenic crustal shortening. It may be significant that there is a correlation between anticlines and synclines and topographic highs and lows respectively.

The pattern of igneous-sedimentary outcrops and accompanying structures is superimposed upon the original dip at the time of igneous activity. Inasmuch as the intrusives antedate the interval of block faulting, the regional dip at the time of igneous activity was southeastward. This does not necessarily apply strictly to the border fault. There, there may have been intermittent movement throughout much of Triassic time. During intervals of quiescence, the surficial sediments building outward from the fault scarp maintained the southeastward regional dip.

The basin pattern suggests slumping such as might be produced if the volume of the igneous intrusives decreased following invasion of the magma. One might attribute this to shrinkage of the cooling diabase. What the percentage decrease in volume would be is questionable. If five percent is assumed there might well be a subsidence of 75 feet. But, such a subsidence, besides being inadequate to account for the structural closures, would presumably be uniform over the whole area. Instead, only parts have been affected. Shrinkage may have been a contributing cause, but not the only one.

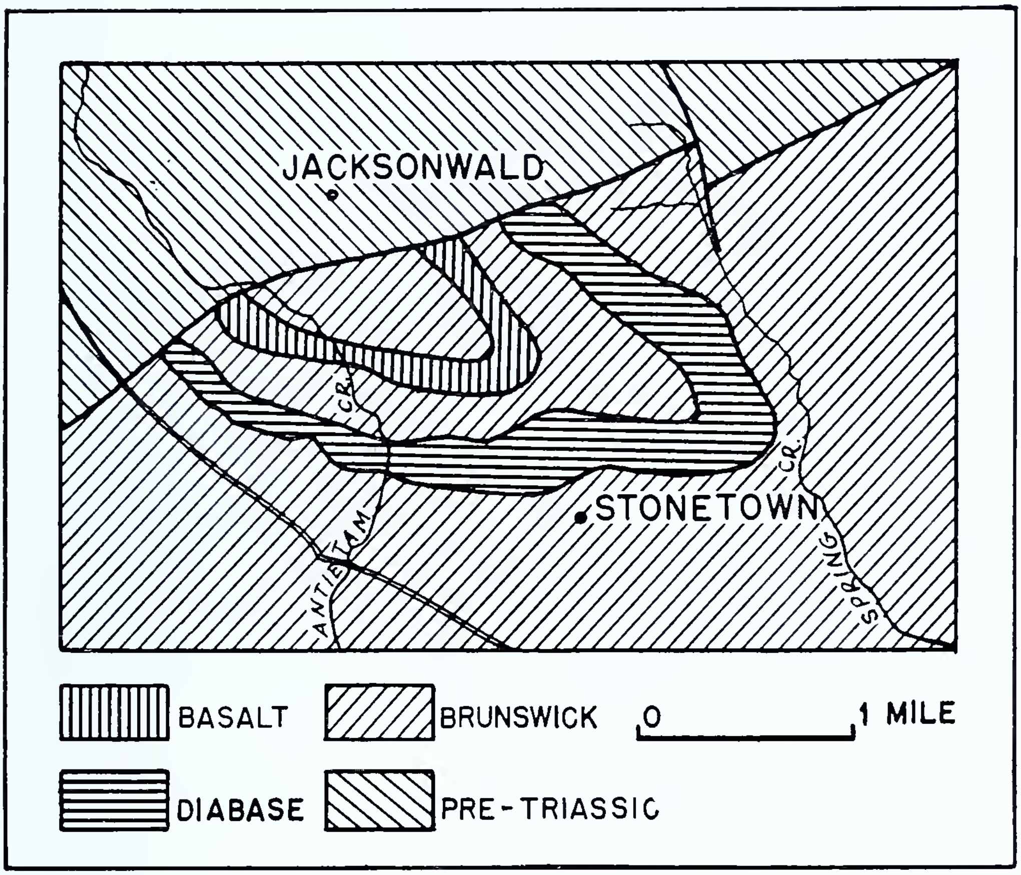
A hint of the cause of the structural pattern may be found in the form of the southeast front of Haycock sheet. Where convexities bend toward the southeast they lie opposite the basins. Conversely, the anticlines aligned more or less perpendicular to the main outcrop are opposite northwestward reentrants. If the lobes represent maxima of advance, accelerated flow or loci of greatest movement of the intruding sheet, then might not the basins form where the magma tended to move out from under? The converse ties the reentrants to the branches as loci of less or least movement. Such movements assume that the source of the magma was at or near the border fault.

Age of the Igneous Rocks

The age of the igneous rocks which intrude the Triassic has been a matter of some discussion. Are they Triassic or younger, perhaps Jurassic? Presumably they cannot be post-Jurassic, since none are reported penetrating Cretaceous sediments. Although the answer may not yet be forthcoming, some deductions can be drawn from present observations.

One mile southeast of Jacksonwald in eastern Berks County an area of about one square mile is underlain by a basalt flow. Although this flow was described by Wherry (1910), it has been restudied at better and newer exposures. The flow forms a hook-shaped body lying within and concentric to a small sheet which is stratigraphically below the flow (Fig. 23, p. 153). The distribution pattern of the two is the same. They occupy the limbs of a small, westward-plunging syncline. These limbs converge eastward as points, but to the westward they diverge and end at or near the Triassic border fault. As one approaches the sill from the south along the highway up Antietam Creek, the baked sedimentary rocks beneath the sill are well exposed in a broad zone, and are seen to be conformable with the base of the igneous rock. The altered zone above the sill is also seen, although the contact with the igneous rock is hidden. Following northward, red beds overlie the hornfels. Then, with practically no altered zone, one again enters igneous rock. This, however, is dense, fine-grained basalt, the base of the flow which is about 500 feet thick. As the road traverses the flow, the rock may be seen to change gradually from dense to amygdaloidal, to vesicular and finally scoriaceous. At a good exposure of the top along the west side of the road, the scoriaceous material has broken down into small boulders cemented by red mud which passes upward into characteristic Brunswick red beds. There is no trace of metamorphism of the beds directly above the flow. Inasmuch as the flow lies within the Brunswick Lithofacies, it is Triassic in age. But, is it the same age as the sheets?

Figure 23



Flow (basalt) and sill (diabase) southeast of Jacksonwald.

There are no radioactive data with which to compare the age of the flow with the intrusive. Wherry's petrographic studies (1910) are uncommunicative on this point. There is no known connection between the flow and sheet. Nevertheless, it seems probable that the two were emplaced more or less contemporaneously. The proximity of the one to the other, the relations to the sedimentary rocks, the pattern of outcrop of sheet and flow and the mutually similar structures are suggestive of contemporaneity.

PETROGRAPHY

by

J. DONALD RYAN

DIABASE

Diabase (dolerite of foreign authors) is a dark-gray to black, hypabyssal igneous rock of basaltic composition, distinguished from other similar rocks by its characteristic ophitic or sub-ophitic texture. Bucks County diabase is typically sub-ophitic. Depending largely upon the rate of cooling, diabase exhibits a considerable range in granularity. In the smaller dikes and in the chilled border zone of larger sills or sheets, diabase is usually dense and aphanitic. Within the larger bodies, grain size usually increases inward passing through a typically phaneritic type and locally into what has been called pegmatitic diabase. Pegmatitic diabase is typically found in the upper interior parts of the thicker sheets. Hotz (1953) has described a pegmatitic diabase at Dillsburg, Pennsylvania, which grades into granophyre. In reviewing the history of usage of the term "pegmatitic" as applied to certain bodies of diabase, Hotz (1953, p. 678-679) stated,

> Characteristically the rock is coarse-grained and the pyroxene crystals, partly altered to amphibole, are long and blade-like, attaining lengths as much as 3 inches. Between the pyroxene blades is chalky white plagioclase in which there may be some pinkish patches of potash feldspar and a little visible quartz. Skeletal crystals of ilmenite-magnetite are abundant.

Tomlinson (1945b) has reported local accumulations of boron-rich pegmatite in Sourland Mountain, but the author (Ryan) has observed no unusually large crystals of augite in Bucks County diabase and consequently does not feel justified in applying the term pegmatite to any of the specimens he studied. It should be pointed out that in most features, except the extremely large size of some augite crystals, certain of the coarser-grained specimens of diabase studied resemble the pegmatitic diabase of Hotz (1953). These coarser types are herein described as coarsely phaneritic. The normal fine-grained, though still phaneritic type, will be referred to as normal phaneritic. This latter type corresponds to the "normal diabase" of Hotz (1953).

Labradorite and pyroxene are the chief essential constituents of diabase. Most of the labradorite crystals are twinned, according to the albite twin law. A few show carlsbad-albite twinning; some show pericline twinning. As in many other diabases, especially in the Triassic of the eastern United States, the most abundant pyroxene is augite but in certain facies, hypersthene and pigeonite also are present. Many specimens, particularly those of phaneritic texture, contain abundant interstitial micropegmatite made up of potash feldspar and quartz. In a few of the coarsely phaneritic specimens, quartz occurs out of contact with potash feldspars. Magnetite and magnetite-ilmenite crystals are more or less abundant, and accessory apatite is always present. Primary hornblende and biotite appear in some of the coarsely phaneritic specimens. In only a few specimens was olivine observed and then only in fine-grained specimens. Biotite, chlorite, hornblende, sericite, actinolite, and tremolite occur as alteration products.

Dikes

Typical diabase from small dikes is extremely fine-grained, dense and, in hand specimen, black. Under the microscope, the average grain size is from 0.1 mm. to 0.7 mm. Diabasic texture is well developed.

Labradorite (An_{70-65}) and augite (with labradorite slightly more abundant) make up about 90 to 95 percent of the rock. Labradorite occurs in twinned laths partially surrounded by colorless augite. Most augite occurs as part of the groundmass but a few microphenocrysts are present. Most of the groundmass augite is untwinned but penetration twins on (100) are common in microphenocrysts. In several dikes, a few microphenocrysts of olivine, partially or wholly replaced by serpentine and lacy crystals of secondary magnetite appear. Primary magnetite and magnetite-ilmenite make up from 5% to 10% of the diabase. These occur in euhedral to subhedral crystals or in interstitial masses. A few grains of apatite are present in most specimens. Flakes of dark-green to brown biotite were found in a number of specimens.

Sheets

Chilled Border Facies

Diabase from the chilled border zone of sheets is essentially similar to that occurring in dikes. In only one specimen was an occurrence of olivine noted. A fine-grained, presumably border zone, specimen from a loose boulder at Coffman Hill contained a single crystal of olivine partially replaced by serpentine.

Normal Phaneritic Diabase

In diabase of the normal phaneritic type the average grain size is 1 to 2 mm. Labradorite and augite again make up 90 to 95 percent of the rock with labradorite slightly more abundant. Labradorite of this zone has essentially the same composition as that of the chilled border zone (An_{70-65}). Hotz (1953) has reported a slightly more sodic labradorite in his "normal diabase" (average An_{62}). Most of the labradorite from Bucks County is relatively fresh but many crystals are slightly altered to sericite or paragonite.

In almost all specimens, colorless to pale-tan augite is the only pyroxene present in diabase of the normal phaneritic type from Bucks County. Penetration twins on (100) are common, and a few herringbone crystals with penetration twins on (100) combined with polysynthetic twins on (100) appear. Hypersthene is absent in most of the specimens examined. When recognized, it is in the form of slightly pleochroic green patches intergrown with augite. Oriented blebs of augite (Hess, 1941) are characteristic.

Generally, the pyroxenes of this group are little altered, although incipient uralitization of augite along cracks and cleavage surfaces is often observed. Biotite, non-uralitic hornblende and chlorite, accompanied by secondary magnetite are also common alteration products of augite. A few cracks in the diabase are filled with pale green tremolite-actinolite.

Interstitial micropegmatite (quartz and potash feldspar), magnetite, and magnetite-ilmenite are usually present in small quantities. Apatite is an ubiquitous accessory.

Coarsely Phaneritic Diabase

In the thicker sheets (Sourland Mountain in New Jersey and Haycock, Solebury and Jericho Mountains in Pennsylvania), the interior portion of the diabase body is considerably coarsened. The average grain size of specimens examined is about 5 mm. The diabasic texture, so prominent in fine-grained specimens, is far less easily recognized in these coarser rocks. Darton (1909b) considered the texture of the Mount Gilboa sill to be granular rather than diabasic. He described the rock as a gabbro. It seems probable that these coarser-grained rocks do represent a trend at least toward true gabbro.

Labradorite and pyroxene make up the bulk of the rock, but pyroxene is slightly dominant over the labradorite. Furthermore, labradorite is slightly more sodic (about AN_{55-50}) than in the finer-grained rocks. Most labradorite is twinned.

Augite is again the dominant pyroxene but considerable hypersthene and a little pigeonite are present. Almost all of the augite is tan in thin-section, and herringbone structure is dominant. Much of the augite is bleached or replaced by green, slightly pleochroic hornblende or chlorite. Hypersthene is found in irregular, slightly pleochroic green patches, intergrown with augite. Oriented blebs of augite occur in the hypersthene. A few colorless inclusions of pigeonite in hypersthene were observed.

Hornblende, almost certainly primary, occurs in small quantities in some specimens. The hornblende is green, slightly pleochroic, and exhibits good amphibole cleavage. That considered to be primary is euhedral, completely divorced from any pyroxene and exceedingly fresh and unaltered.

Micropegmatite and locally quartz are present in small quantities but are more abundant than in normal phaneritic diabase.

Magnetite and magnetite-ilmenite, often in large patches, are present in minor amounts. Apatite needles are contained in all specimens.

The similarity between these coarsely phaneritic diabases and the pegmatitic diabase of Dillsburg (Hotz, 1953) is remarkable. Only the presence of primary hornblende in diabase from Bucks County is distinctive.

Hydrothermal Veins

Crosscutting veins of various compositions are present in many Triassic diabases of the eastern United States. Shannon (1924) describes diabase aplite and diopside-hornblende veins at Goose Creek, Virginia. Tomlinson (1945b) mentions the presence of an association of prehnite, epidote and actinolite in rubble on the floor of the Lambertville, New Jersey, quarry. It is inferred that these minerals occur in veins.

Veins of actinolite, prehnite and albitite are fairly prominent in the Cooperburg and Rock Hill Quarries of the Haycock diabase sheet. No specimens were studied by the author.

Chemical Analyses

No chemical analyses were made as a part of this study. For purposes of comparison, an analysis of diabase taken from Rocky Hill by Phillips (1899) is reproduced in Table 32 (p. 157) along with several analyses of other basaltic rock types.

TABLE 32. *Analyses of basaltic rocks*

	1	*2*	*3*	*4*	*5*
SiO_2	56.78	51.33	50.66	50	45
Al_2O_3	14.33	14.79	14.28	13	15
Fe_2O_3	5.76	1.85	3.41	13	13
FeO	9.27	8.32	8.58		
MgO	1.58	7.23	6.92	5	8
CaO	5.26	10.51	8.60	10	9
Na_2O	3.43	1.94	2.92	2.8	2.5
K_2O	1.75	0.57	0.72	1.2	0.5
H_2O+	.43	1.49	2.28		
H_2O-		0.46			
TiO_2	1.44	1.16	1.30		
P_2O_5	.36	0.14	0.17		
MnO	.25	0.17	0.12		
Total	100.64	99.96	99.96	95	93

(1) Diabase from Rocky Hill (Phillips, 1899).
(2) Diabase from Dillsburg, Penna.; specimen 284 (Hotz, 1953).
(3) Average of 8 New Jersey basalts (Washington, 1922).
(4) Tholeitic magma-type (Kennedy, 1933).
(5) Olivine-basalt magma-type (Kennedy, 1933).

It has been repeatedly pointed out that some variation in the composition of parent basaltic magmas is indicated by comparison of chemical analysis of basaltic rocks. Kennedy (1933) has distinguished two magma-types, (1) a tholeitic type which is apparently the parent magma of the quartz-bearing diabase and (2) an olivine-basalt type which is apparently the parent of the olivine-basalt trachyte association.

Clearly, the Triassic diabases of Bucks County have sprung from the tholeitic magma-type. This is apparently true of all eastern United States Triassic intrusive bodies.

Crystallization of the Diabase

Although most of the dikes and sheets in Bucks County are too small to show the effects of differentiation, the larger sheets (Haycock and Sourland, New Jersey sheets) show certain definite trends. With increasing grain size toward the interior portion of these bodies, definite and related changes in mineral composition take place.

The minerals in dikes and chilled border facies of the larger sheets are probably the original minerals to crystallize out from the tholeitic magma. Rapid cooling would cause freezing of the melt before much differentiation was possible. Thus olivine microphenocrysts, although rarely present, would be the earliest minerals formed. Probably soon thereafter, augite, a relatively magnesium-rich pyroxene, which also is present in microphenocrysts, began to form and was followed by simultaneous crystallization of augite and basic labradorite.

Crystallization of the more slowly cooled, normal phaneritic diabase was not completed until a more iron-rich pyroxene, hypersthene, was forming with augite in the melt. At the same time, labradorite of slightly more sodic composition than that of earlier stages continued to crystallize.

Near the final stage of pyroxene and plagioclase crystallization, as represented by coarsely phaneritic diabase, hypersthene and augite (possibly titaniferous) continued to crystallize together, but some of the hypersthene contains oriented blebs and plates of augite. Pigeonite inclusions in hypersthene of the coarsely phaneritic diabase probably formed by inversion of hypersthene (Hess, 1941, p. 580-581). Hornblende is formed at a relatively late stage, probably chiefly by reaction of the magma with pyroxene. About the same time magnetite and magnetite-ilmenite were formed. Relatively sodic labradorite was produced during this stage of crystallization.

The last liquid to crystallize was a potash and silica-rich residuum which formed interstitial micropegmatite.

The trend of pyroxene crystallization is essentially the same as that proposed by Hess (1941) as being the normal trend in diabase. Relatively magnesium-rich pyroxene appears early and is later replaced by relatively iron-rich pyroxene. In Bucks County the trend toward an iron-rich liquid at this stage is also shown by the presence of hornblende and interstitial magnetite-ilmenite. The iron-rich liquid was also somewhat enriched in titanium.

SYENITES

The term syenite is herein used to describe a somewhat variable group of white or pink, phaneritic and granular rocks made up primarily of potash feldspars, oligoclase, and an unidentifiable highly altered plagioclase. Quartz, in micropegmatitic intergrowths or as discrete crystals, never exceeds 5 percent.

Mafic minerals never make up more than 25 percent of the rock and typically less. Brown hornblende is the dominant mafic mineral but some specimens contain only alteration products of the hornblende, or only augite and its alteration products.

Magnetite, magnetite-ilmenite and apatite are the usual accessory minerals.

The best exposures of syenite are in New Jersey.

In the Reading Railroad cut at the Northampton County line northwest of Hilltop, syenitic material occurs in the lowermost portion of the main diabase sheet. The edge of the diabase sheet is considerably fractured and jointed, and in many of the fractures finger-like fillings of white syenitic material sharply contrast with the dark diabase. Walker (1940) has described similar veins in both upper and lower chilled border facies of the famed Palisades sill, New Jersey. In the railroad cut, patches of syenitic rock apparently related to the fractures grade imperceptibly into diabase. Northwest of Hilltop on Route 309, similar, poorly developed syenitic patches may also be observed.

Pyroxene Syenite

One specimen of pyroxene-bearing syenite was studied. The bulk of the rock is made up of heavily altered zoned plagioclase. Some of the crystals have been completely replaced by pistacite and sericite (?). Other crystals, completely replaced in their interior portions, are rimmed with clear, practically unaltered oligoclase. Laths of oligoclase and irregular patches of perthitic potash feldspar are also present.

The composition of the heavily altered feldspars, although not directly determinable, must have been such that these crystals were unstable during the period of crystallization of the more acid feldspars. Almost certainly, these feldspars are more basic than oligoclase. Probably they are labradorite in composition.

A few crystals of almost entirely replaced purple-brown augite (probably high in titanium) occur in the rock. Usually the edges of the little remaining augite are in contact with biotite. Biotite grades outward into a complex mixture of biotite, chlorite and large quantities of fibrous, pleochroic green actinolite. Patches of pistacite and secondary magnetite and quartz are associated with the actinolite. In several areas actinolite alone, pseudomorphic after augite, is found.

Some interstitial rutilated quartz in small quantities and one euhedral crystal of rutilated quartz is present. Unusually long acicular apatite crystals are enclosed by much of the feldspar.

Hornblende Syenite

Most syenites, including the vein fillings in the lower chilled zone of Haycock sheet, are hornblende syenites.

These rocks are also composed of 75 percent or more feldspar of several types. The most abundant is a feldspar almost completely altered to sericite (?). In almost all specimens, these highly altered feldspars occur as laths sharply separated from adjacent minerals. Presumably, as in the foregoing specimens, these feldspars are highly altered labradorite.

The second most abundant feldspar is a perthitic potash feldspar occurring generally in laths or patches. Some of the specimens are also broken up by numerous potash feldspar filled fractures which cut across all other minerals. A few laths of oligoclase are also present.

The most characteristic mineral of this rock type is euhedral brown hornblende, pleochroic and grading in color from dark-green along thin borders to vivid red-brown in the interior. The crystals are entirely fresh and unaltered.

Wisps of primary, dark-brown, highly pleochroic biotite are present in small quantities. Most are partially altered to chlorite and secondary magnetite. Some biotite surrounds apparently primary magnetite and magnetite-ilmenite.

Interstitial micropegmatite forms a few small aggregates. Euhedral acicular apatite is a minor accessory.

Biotite Syenite

Biotite syenites appear to be highly altered equivalents of the hornblende syenites. The only amphibole present (presumably originally hornblende) appears as highly bleached, almost isotropic remnants in which only the typical prismatic or basal forms are recognizable. Dark-brown, iron-rich biotite and minor actinolite replace most of the amphibole. Aggregates of secondary pistacite are also abundant.

Nepheline Syenite

Ransome (1899) who first described the syenite occurrence at Mount Gilboa reported several specimens of nepheline syenite at that locality. No specimens of this type were observed by the author.

Origin of the Syenites

There are three possible ways by which the syenite could have accumulated in the diabase sheets. (1) It is possible that during its ascent, the parent basaltic magma could have passed through a deeply buried syenite mass and carried syenite xenoliths upward. This view was held by Ransome (1899) primarily because of the great difference in composition of the syenite and enclosing diabase. (2) The syenites conceivably could have been formed by late hydrothermal replacement of previously crystallized diabase. Support for this view might be occasioned by the presence of local albitites bordering a number of presumably hydrothermally emplaced veins of actinolite and prehnite cutting some of the diabase sheets in the area. (3) Finally, it is possible that the syenite is a late differentiate of the parent basaltic magma from which the diabase crystallized. If this is the origin, the trend of differentiation observed within the diabase should be continued within the syenites.

In the author's opinion, there is little evidence to support either (1) or (2) above and considerable to dispute them. The syenites are almost certainly late differentiates of an originally basaltic magma.

It would be most fortuitous if deeply buried syenites, a rather uncommon rock type, were to occur below the sheets, especially inasmuch as pre-Triassic rocks of this composition are rare in this region. Furthermore, the occurrence of syenite at Mount Gilboa is much too large to be a xenolith.

The abundance of euhedral crystals and the apparent lack of any widespread relict ophitic texture strongly suggests primary crystallization rather than replacement. Where obvious replacement has taken place, as in the sericitized or paragonitized labradorite (?) or highly altered augite, discrete crystals have been affected. It seems apparent that isolated labradorite and augite crystals, formed during the main period of diabase crystallization, were entrapped in a late residual liquid from which the main body of syenites was evolved.

As visualized by the author, the origin of the syenite is as follows:

Crystallization of the coarsely phaneritic diabase facies in the thick sheets nearly used up the last of an originally basaltic magma. In certain areas, however, a liquid enriched in potash, soda, alumina, silica, iron, and some titanium remained. Some of this liquid congealed around and altered earlier crystallized pyroxenes and plagioclases. The final product was a variable series of syenites.

METAMORPHIC ROCKS

Sedimentary rocks of the Newark Group have been metamorphosed to hornfels where they are in contact with the diabase intrusive bodies. There is considerable variation in width of the metamorphosed zones. Poor exposures in the vicinity of the smaller dikes preclude accurate measurements of the metamorphic zones in these areas but, presumably, they are extremely narrow. In general, the larger sheets have thicker metamorphic haloes, but within this group, the size of the metamorphosing intrusive body is not the determining factor. Variations in thickness within a single zone, as along the southern flank of Haycock sheet, are common. Probably the most important factor determining the thickness of the metamorphosed zone is composition of the sedimentary rock.

Hornfels is a hard, dense, gray to black rock formed by the complete or partial recrystallization of fine-grained, usually argillaceous sedimentary rocks. Original structures such as bedding are often retained and easily identified. Characteristically, the metamorphic minerals are either arranged in a haphazard unoriented fashion or follow some relict structure. Consequently, hornfels is almost never laminated. In some specimens, ovoid aggregates of certain metamorphic minerals impart a "spotted" appearance to the rock. Hornfels is often difficult to distinguish from the black argillite of Lockatong Lithofacies. In some places microscopic study is necessary to distinguish a metamorphosed argillite from the unaltered sedimentary rock.

Recrystallization in hornfels in Bucks County has, in general, proceeded along these lines:

(1) Partial reduction of ferric iron to ferrous iron with crystallization of magnetite. This change is primarily responsible for the difference in color between red shale and hornfels of Brunswick Lithofacies.

(2) Recrystallization of quartz causing changes in the original detrital texture of the quartz grains.

(3) Recrystallization of argillaceous material producing sericite, muscovite, chlorite, biotite, cordierite, calcite, and epidote.

Metasomatic changes are thought to be minor.

Three zones within the metamorphic aureoles each characterized by its own set of minerals can be recognized. However, because of differences in the primary composition of the sedimentary rocks, the zones are somewhat variable.

Zone of Sericite

The first indication of contact metamorphism of Brunswick Lithofacies is a conspicuous darkening. The original brick red color of these rocks becomes purple, then black or gray. Black argillites of Lockatong Lithofacies show no megascopic change.

At the edge of the contact aureole where discoloration begins, the rock is characterized by the presence of haphazardly arranged shreds of sericite which become more abundant toward the diabase. The original hematite of Brunswick Lithofacies is partially reduced and magnetite ($Fe_2O_3.FeO$) forms. Quartz retains its detrital outline and apparently is virtually unchanged.

At the edge of the Point Pleasant contact aureole, numerous rhombs of calcite are present. Apparently the black argillite, at least in this area, is somewhat calcareous.

Zone of Muscovite

The zone of sericite gradually gives way to a zone in which muscovite (actually mature crystals of sericite) is the dominant new mineral. Within this zone, quartz begins to recrystallize. Many detrital grains show overgrowths and, in its last stages, pods of recrystallized quartz develop. These pods may impart a slightly spotted appearance to polished surfaces.

Locally a little biotite and chlorite are present.

Zone of Biotite and Cordierite

Under the sill at Byram, New Jersey, metamorphosed argillites of Lockatong Lithofacies contain abundant stubby flakes of highly pleochroic brown biotite with a little chlorite. Generally, the biotite is disseminated throughout the rock, but it also forms in clusters surrounding tiny ovoid crystals of cordierite. A little epidote replaces some of the cordierite. Quartz is recrystallized and retains little of its original detrital form.

This assemblage of minerals is typical of potash-poor sediments which have reached the cordierite-anthophyllite subfacies of Eskola's metamorphic amphibolite facies (Turner, 1948, p. 78-79).

Jonas (Bascom and others, 1931, p. 36-37) has described nodules of epidote pseudomorphic after cordierite in metamorphosed shales of Brunswick Lithofacies just under Haycock sheet in the railroad cut south of Solford station. These nodules have produced markedly spotted hornfels. The author has observed this rock but has not had an opportunity to examine it in thin section.

CHAPTER V

LATE PLEISTOCENE DEPOSITS

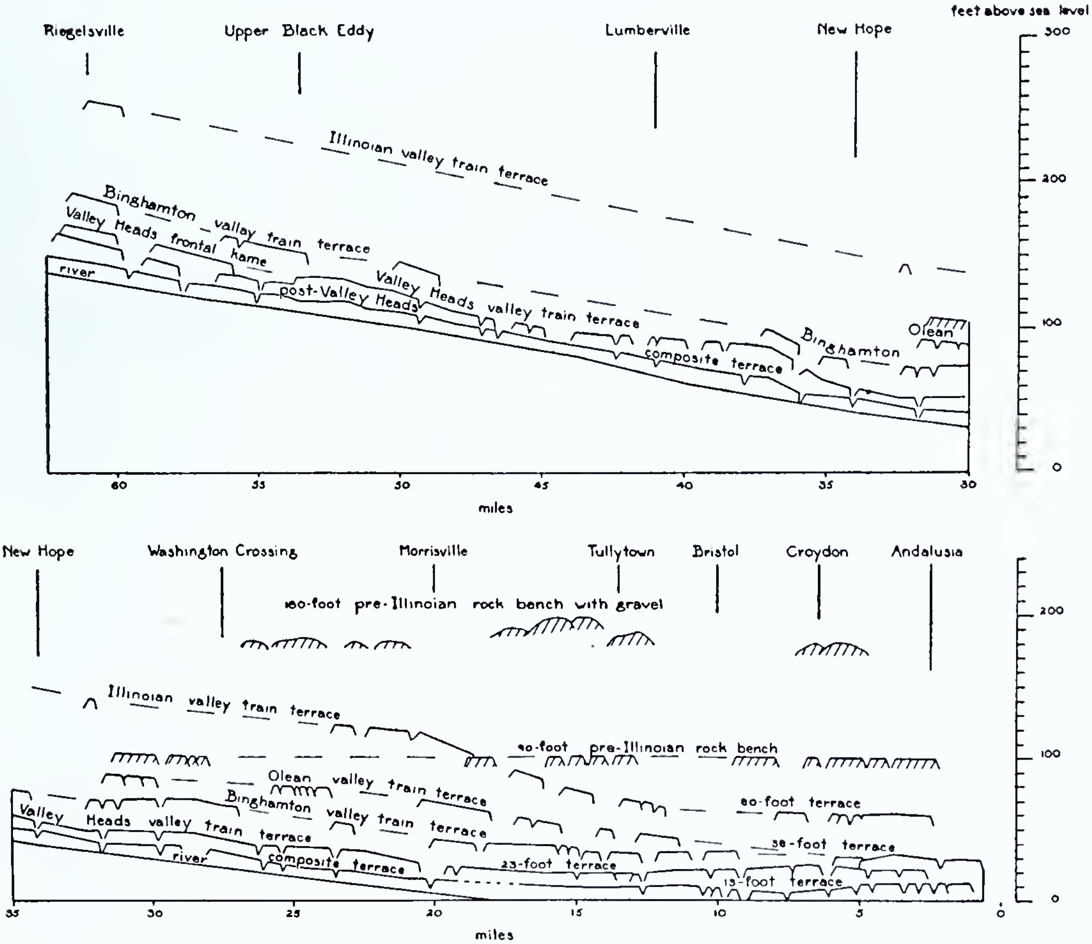
by

LOUIS C. PELTIER

INTRODUCTION

During the glacial episodes of the Pleistocene, Bucks County lay just beyond the outer edge of the continental ice and, because of the proximity of this ice, the climate was distinctly cold. The Delaware River was choked with sand and gravel swept seaward from the ice front. Other streams, such as Neshaminy Creek and Poquessing Creek, which rise in hills beyond the glacial limits, carried no outwash but likewise were choked with rubble derived from the sparsely covered hillsides. Accordingly, glacial stages and sub-stages are represented by periods of aggradation of stream valleys with either glacial outwash or periglacial debris.

FIGURE 24



Profile of Delaware River showing the grade lines of the various Pleistocene terraces.

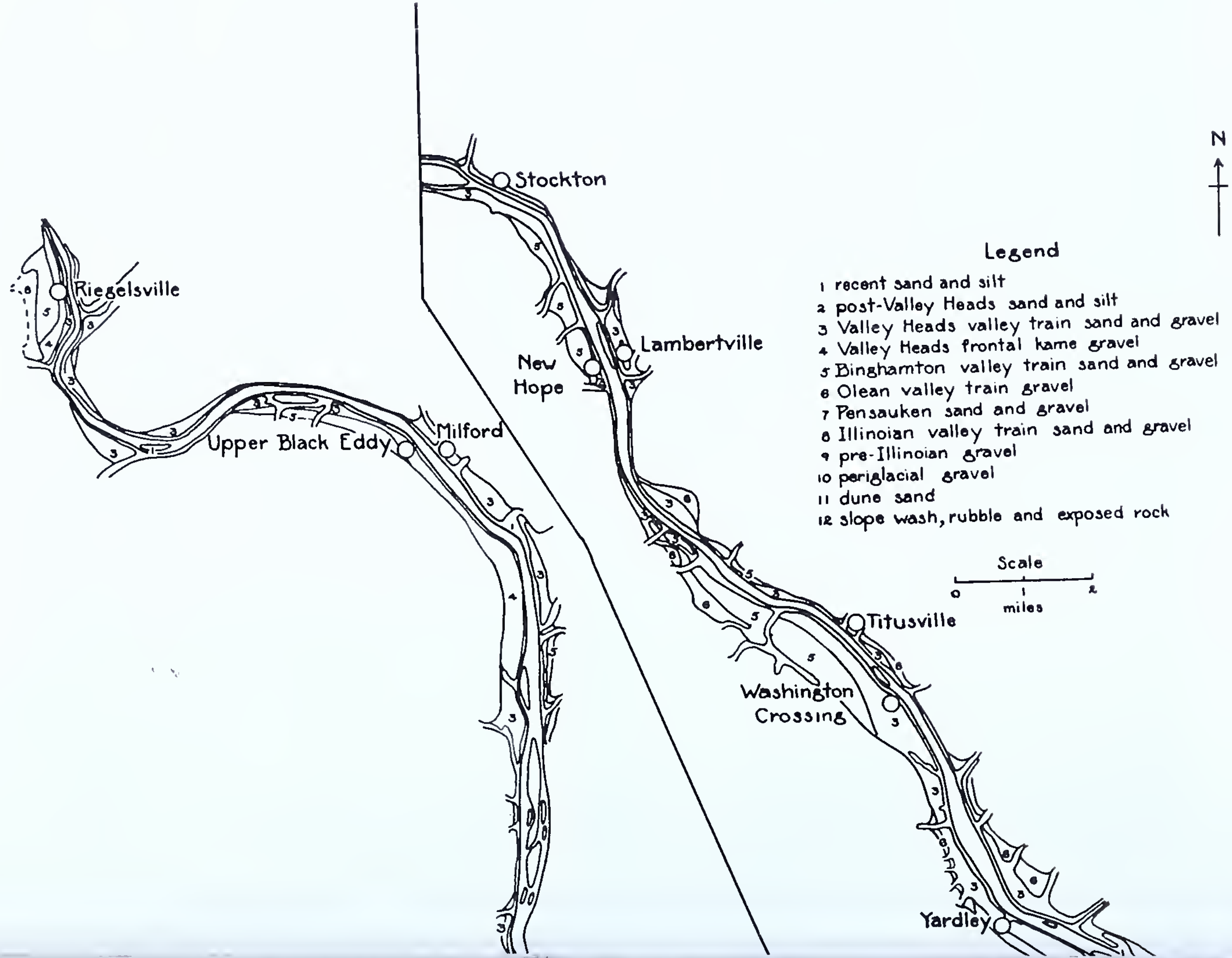
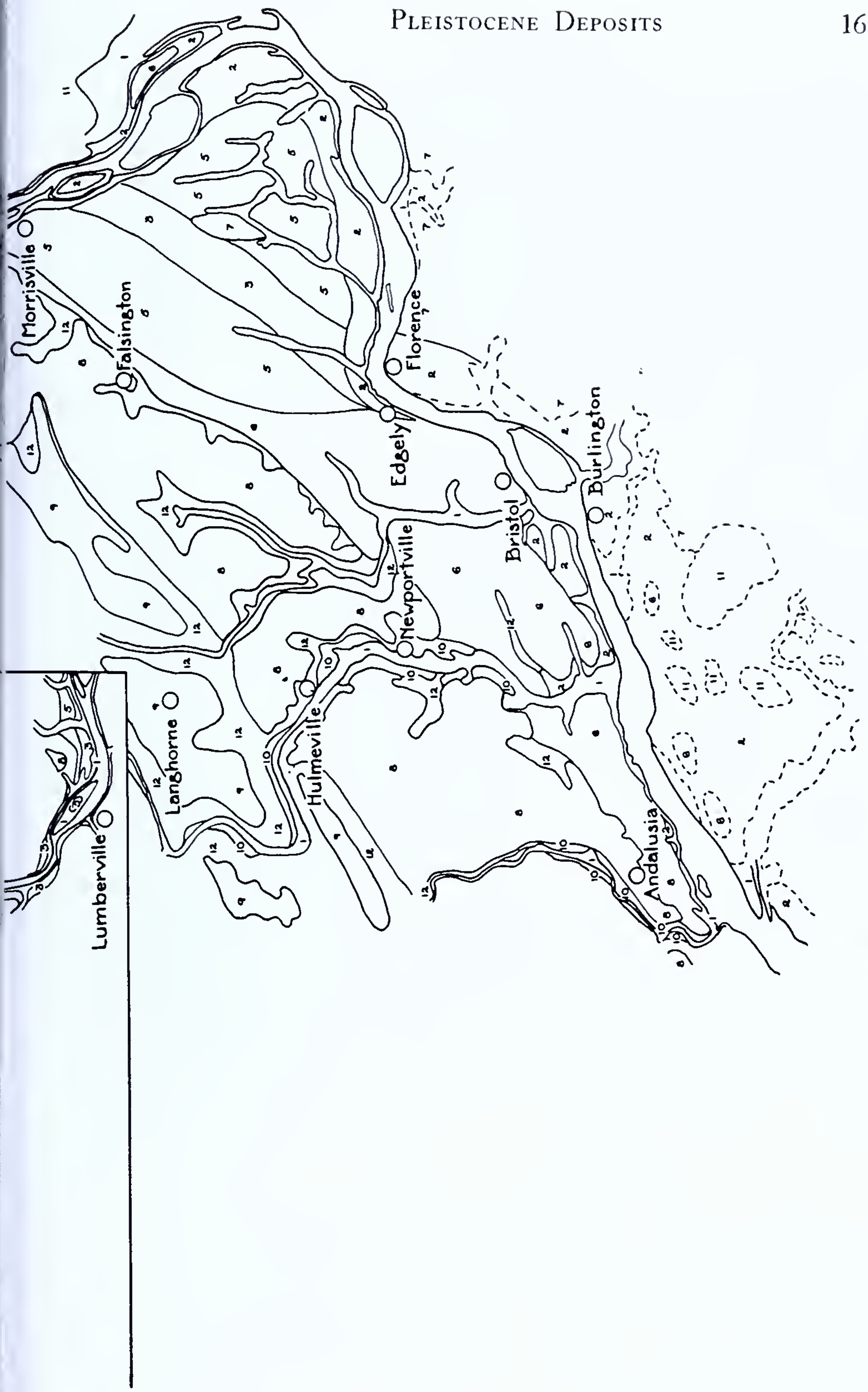

N
Legend
1 recent sand and silt
2 post-Valley Heads sand and silt
3 Valley Heads valley train sand and gravel
4 Valley Heads frontal kame gravel
5 Binghamton valley train sand and gravel
6 Olean valley train gravel
7 Pensauken sand and gravel
8 Illinoian valley train sand and gravel
9 pre-Illinoian gravel
10 periglacial gravel
11 dune sand
12 slope wash, rubble and exposed rock
Scale
0
1
2
miles
Stockton
Lambertville
New Hope
Riegelsville
Upper Black Eddy
Milford
Titusville
Washington Crossing
Yardley

FIGURE 25



Map of Pleistocene deposits in Bucks County.

The climate of the intervals between glacial episodes was relatively mild, at some times probably warmer than that of the present. During these times the forest, destroyed at the beginning of the glacial episode, reappeared, retarding the flow of water from the hillslopes and stabilizing them against mass wastage. The choking of the streams by rubble ceased because the gravity and size of particles carried by run-off from slopes and small tributaries diminished. With load reduced, streams were able to cut down into the gravel fills deposited during the colder glacial periods. Remnants of these valley-fill deposits form the Pleistocene terraces along the major streams in Bucks County. A detailed plot of the terrace remnants is shown in Figure 24 (p. 163). This diagram is a modification and expansion of a similar study made by Salisbury (1902).

PLEISTOCENE DEPOSITS

Pre-Illinoian Deposits

The earliest Pleistocene deposits recognized in Bucks County (Figure 24, p. 163) consist of scattered boulders, thin bodies of silty gravel, and scattered pebbles and cobblestones mixed with Wisconsin loess and fragments of frost-shattered rock. These deposits occur on a rock bench 180 to 220 feet above sea level (Figures 24, p. 163 and 27, p. 170). They consist largely of pebbles of quartz, quartzite, sandstone, and chert similar to those in conglomerate of Stockton Lithofacies. No pre-Illinoian gravel has been definitely identified overlying Stockton Lithofacies, and the northwestern boundary of these deposits, shown in Figure 25 (p. 165) is therefore uncertain. However, similar gravels, found overlying schist or gneiss on the rock bench 180 to 220 feet above sea level, are probably pre-Illinoian in age. Such a gravel is exposed in the railroad cut at Dunlap, five miles west of Morrisville. Here, beneath a thin podsolized silt loam, lies a yellowish-brown, compact, jointed, pebbly sand. The stratigraphic section of this deposit is described in detail in Table 33 (p. 164). The pebbles, consisting of milky quartz, gray, white, and pink quartzite, and gray sandstones, are well-rounded and could not have been derived from the underlying rock. However, the angular fragments of quartz and schistose quartzite in this deposit are probably of local derivation.

TABLE 33. *Stratigraphic section of railroad cut on the north side of Trenton Cutoff five miles west of Morrisville*

Horizon	*Description*	*Thickness*	
		Feet	*Inches*
1.	Loam, light-gray, silty, powdery, with grass roots. A_0 – horizon	0	6
2.	Loam, ash-gray, silty, lumpy, friable. Gradational contact with horizon 3. A1 - horizon	0	8
3.	Sand, yellowish-brown, fine-grained, clayey, with scattered, well-rounded pebbles of quartz and quartzite. Jointed with gray bleaching along joints giving a mottled effect. B-horizon	1	10
4.	Sand, yellowish-brown, fine-grained, well-sorted, compact, lumpy. Contains angular quartz fragments	2	5
5.	Slumped to base of cut	10	0
	Total	15	5

Illinoian Glaciation

Illinoian glacial ice extended as a tongue down the Delaware Valley and penetrated northeastern Bucks County in the vicinity of Riegelsville. Deposits of this stage occur there as bodies of rubified (reddish-brown), clayey gravel, till, or scattered pebbles. They are most prominent in extreme northern Bucks County along the Delaware River at Riegelsville and along Durham (Cook) Creek. This creek acted as a drainage outlet for Illinoian meltwaters which flowed across the spillway on the southwestern side of Bougher Hill, northwest of Riegelsville in Northampton County (Leverett, 1934).

Illinoian Gravel Outwash

Deposits of reddish-brown poorly-sorted, compact, clayey, and silty gravel occur extensively on the valley walls in the vicinity of Morrisville. A typical exposure of this gravel is exposed along the Trenton Cut-off of the Pennsylvania Railroad, two miles southwest of Morrisville (Table 34, below). At this locality a thin deposit of Wisconsin loess lies upon compact, rubified Illinoian sand and gravel. A pebble sample shows that the gravel (Table 35, p. 168) has an unusually high proportion of quartz pebbles, owing either to a severe period of weathering of Stockton Lithofacies immediately preceding the Illinoian glacial stage, or to some, as yet unrecognized, source of local contamination.

Table 34. *Stratigraphic section of railroad cut on the north side of Trenton Cutoff two miles southwest of Morrisville at Falsington.*

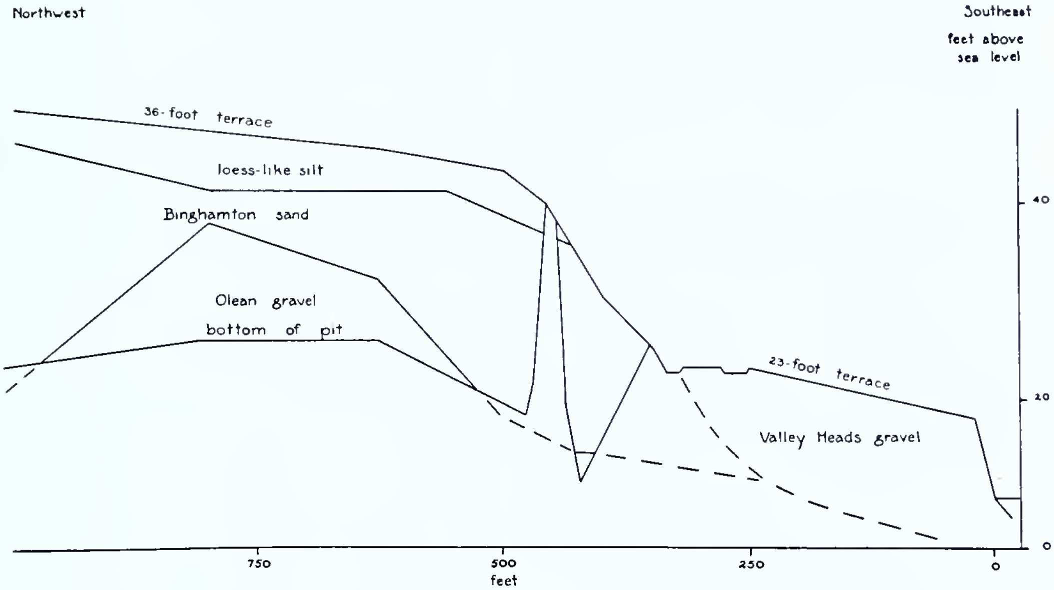
Horizon	*Description*	*Thickness*	
		Feet	*Inches*
1.	Loam, light-gray, silty, loose, friable. A-horizon	0	6
2.	Loam, grayish-brown, silty, loose	0	4
3.	Loam, buff, silty, loose but more compact than horizons 1 and 2. A-horizon	0	10
4.	Loam, buff, silty, slightly compact. Base indistinct and not observed. A Wisconsin loess deposit. B-horizon	1	10
5.	Sand, reddish-buff, medium-grained, clayey. This horizon appears to have been rubified and then, at a later time, bleached to a lighter color	3	6
6.	Sand, reddish-brown, well-sorted, clayey, rubified	1	6
7.	Gravel, reddish-brown, poorly-sorted, in a matrix of clayey sand, rubified. Contains numerous cobblestones and small boulders	4	0
8.	Covered to base of cut	11	6
	Total	24	0

Elsewhere, near Morrisville, the deposits are 25 to 30 feet thick. The edge of these deposits toward the Delaware River slopes seaward, as shown in Figure 24 (p. 163) from a height of 120 feet above sea level near Morrisville to a height of 80 feet near Cornwells Heights at a rate of about six feet per mile. Other similar deposits lie upon a rock bench 80 to 130 feet above the Delaware estuary. The surface of these deposits slopes seaward about 2½ feet per mile from near Morrisville. These deposits have been shown on the map (Figure 27, p. 170) forming two rock benches about 90 and 120 feet above sea level, rather than one that slopes steeply toward the river. Since the pre-Wisconsin terraces

TABLE 35. *Pebble counts of Pleistocene deposits in the Delaware Valley*

Age	*Illin-oian*	*Pen-sauken*	*Olean*						*Binghamton*			*Valley Heads*		
Place	*Falsington*	*Turkey Hill*	*Penn Valley*	*Wheat Sheaf*	*Croydon*	*Newportville*	*Neshaminy Creek*	*Riegelsville*	*Wheat Sheaf*	*Falsington*	*Penn Valley*	*Upper Black Eddy*	*Wheat Sheaf*	*PennValley*
Gray sandstone and siltstone	16.6	28.6	20.9	22.3	22.0	33.0	31.6	36.3	8.7	21.8	8.8	22.8	17.6	23.4
Red sandstone and shale	3.7	7.8	4.0	5.9	15.4	7.9	6.8	3.3	5.5	5.1	5.5	4.0	5.7	3.0
Limestone and dolomite	...	...	...	...	...	...	...	39.6	...	...	...	33.6	...	11.2
Chert	12.9	10.0	4.0	4.9	6.0	4.4	3.4	3.7	10.6	9.3	10.6	4.9	4.4	8.6
Concretionary limonite	...	4.3	...	...	...	...	...	...	...	...	...	...	...	...
Quartz	38.8	26.1	7.7	6.4	18.2	14.5	16.6	...	9.2	4.1	7.4	2.2	6.6	2.5
Quartzite	9.2	9.5	35.0	26.3	30.3	25.5	20.1	5.3	26.9	37.2	26.9	28.2	28.6	30.6
Granite and gneiss	2.7	1.7	1.8	1.4	5.5	1.7	1.7	3.7	5.0	4.1	7.4	2.6	5.2	4.0
Diabase	0.4	1.3	2.8	1.4	...	2.2	2.8	...	0.9	1.3	2.2	1.3	2.2	1.0
Other	15.6	9.6	26.3	32.3	2.2	12.7	19.5	7.3	33.7	18.0	32.9	...	31.6	15.3
Total percent	99.9	99.2	99.7	99.5	99.6	99.7	99.7	99.2	99.6	99.6	99.5	99.6	99.7	99.6
Total pebbles	216	230	220	201	181	227	174	242	216	215	215	223	227	196

FIGURE 26



Geologic cross-section of Tullytown Sand and Gravel Company"s pit showing contact between Olean and Binghamton gravel deposits.

diverge in height downstream, it is not clear whether they represent different episodes of alluviation or merely the fluvial erosion of a single deposit. These gravels are well exposed in a road cut on U. S. Highway 1, three-quarters of a mile east of South Langhorne, where rubified gravel about 20 feet thick lies upon a rock bench cut in Wissahickon Schist about 90 feet above sea level.

Upstream, the Illinoian stage is represented by relatively thin deposits of gravel and scattered, rounded stones upon rock benches 120 to 140 feet above the Delaware River.

Pensauken Sand and Gravel

The Pensauken sand and gravel consists of yellowish-brown gravel and yellowish-brown, brown, and greenish-yellow sands. The gravel, in some bodies, is granule in size and well-sorted; other deposits range from pebbles to boulders. At Turkey Hill, three miles south of Morrisville (Figure 28, p. 174), is a surface deposit of sandy loam about four feet thick underlain by a deposit of compact, medium-grained dark-brown sand and pebbly yellow gravel in a sand matrix believed by the writer to be Pensauken sand and gravel (Table 36, p. 171). A pebble sample shows that the gravel differs only by the presence of a small amount of concretionary limonite from other gravels in the area (Table 35, p. 168).

The material in this gravel is as vulnerable to rubification as that in the Illinoian deposits. The absence of rubification here indicates that the deposit was not subjected to the processes which produce rubification. If the gravel is truly Pensauken, it must be concluded either that a peculiar set of environmental conditions in post-Illinoian time caused the gravel to lose any red color it might have had, or that the gravel was not deposited until after the time of post-Illinoian rubification. There is no reason to believe that the environmental conditions associated with the deposition or weathering history of the Pensauken

Figure 27

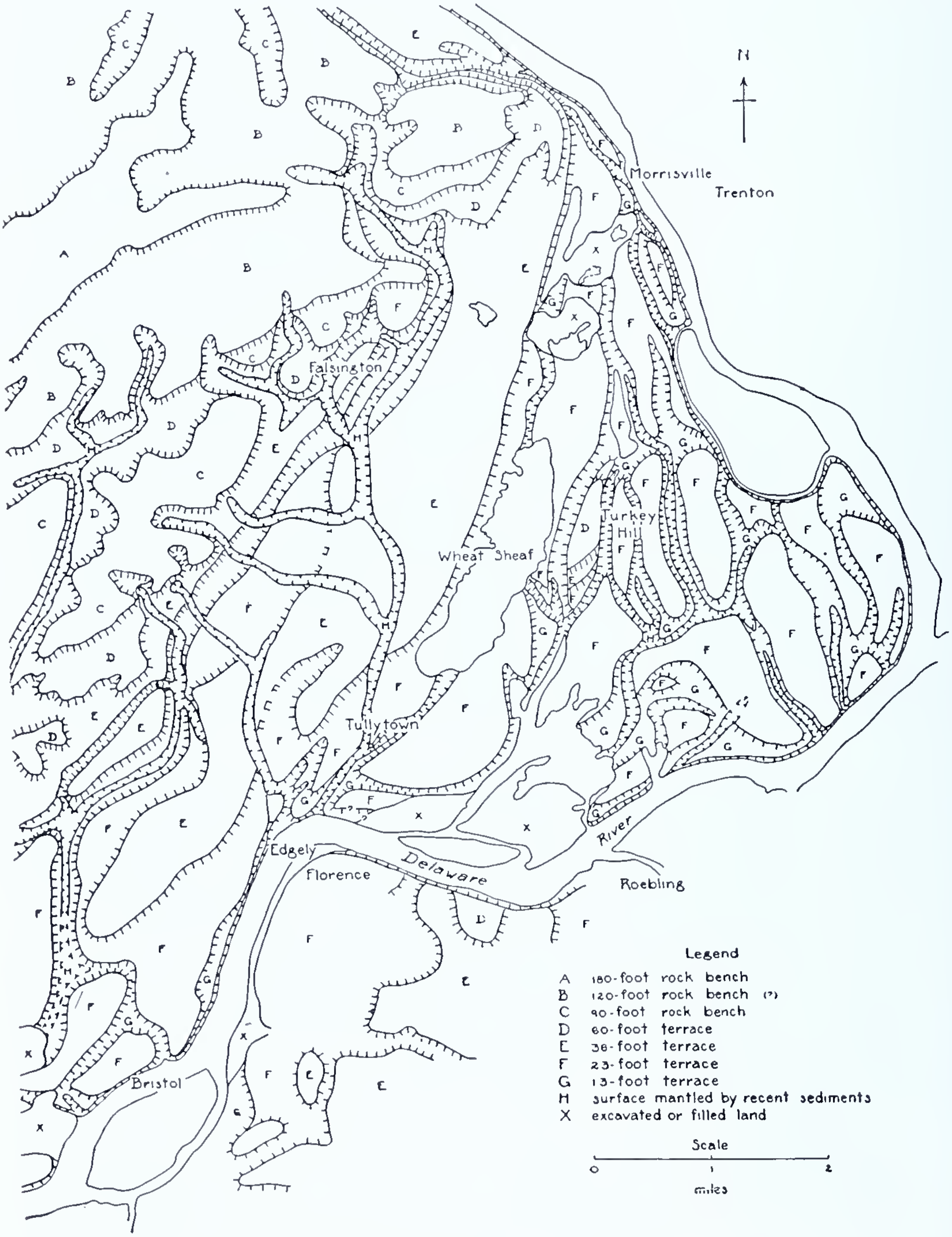


Diagram of terraces in vicinity of Morrisville and Bristol.

TABLE 36. *Stratigraphic section of abandoned borrow pit on the south side of Turkey Hill, three miles south of Morrisville*

Horizon	*Description*	*Thickness* *Feet*	*Inches*
1.	Loam, light-gray, very fine-grained, sandy, loose-textured, with grass roots, pebbly A_1 – horizon	1	0
2.	Loam, buff, very fine-grained, sandy, compact. B_1 – horizon	0	9
3.	Loam, light-brown, sandy, pebbly, compact. B_2 – horizon	1	0
4.	Sand, light-tan, fine-grained, silty, pebbly in places, scattered cobblestones, loose-textured. Probably a windborne sand which has been disturbed by frost-heaving	1	8
5.	Sand, dark-brown, very compact, indurated. Has sharp contact with horizon 4	0	8
6.	Sand, brownish-buff, fine-grained, silty, very compact	0	0 to 5
7.	Gravel, dark-brown, fine-grained, in a matrix of medium- to coarse-grained sand. Top undulating with relief of 8 to 10 inches	0	8
8.	Sand, yellowish-brown, fine-grained. Interbedded with two- to three-inch thick layers of coarse-grained, dark-brown sand	2	5
9.	Sand, grayish-brown, medium-grained, silty	1	0
10.	Gravel, yellowish-brown, fine-grained, in a matrix of medium-grained sand. Resembles Pensauken gravel of southern New Jersey	1	6
11.	Sand, greenish-yellow, very fine-grained, well-sorted. Merges with the gravels of horizons 10 and 12	0	6
12.	Gravel, brown and fine- to medium-grained sand, poorly-sorted, in a matrix of medium-grained sand. Oxidized, non-calcareous	3	0
13.	Covered to base	5	0
	Total	19	7

sand and gravel in Turkey Hill were unique or peculiar. It is, therefore, concluded that the deposit never was subjected to rubification and is younger than the rubified Illinoian deposits. The weathering of this possible Pensauken sand and gravel appears intermediate in intensity between that of the Illinoian deposits and that of Wisconsin deposits. It must, therefore, have been deposited along the Delaware Valley during a post-Illinoian time of alluviation. Deposits of similar coarseness along the Delaware River were laid down during cold or glacial episodes. The Pensauken sand and gravel of Turkey Hill, by this comparison, may have been laid down during a cold interval between the Illinoian and previously recognized earliest Wisconsin deposits in the area.

Olean Gravel Outwash

The general characteristics of the Olean outwash are represented in the basal gravel exposed in the pit of the Tullytown Sand and Gravel Company at Wheat Sheaf in 1949 (Table 37, p. 172). This material is a brown, poorly-sorted, dirty, sandy gravel with numerous boulders and resembles a periglacial gravel rather than a well-washed valley-train gravel. The Olean gravel is capped by a thin deposit of compact, silty Binghamton sand and is markedly different in appearance from the light-gray, pebbly sands and gravels overlying the Binghamton

TABLE 37. *Stratigraphic section in the pit of the Tullytown Sand and Gravel Company at Wheat Sheaf, 1.6 miles northeast of Tullytown*

Horizon	*Description*	*Thickness*	
		Feet	*Inches*
1.	Fill from pit operations	0	5
2.	Loam, dark-gray, sandy, loose, friable, pebbly, slightly carbonaceous. A-horizon	0	4
3.	Loam, grayish-brown, sandy, pebbly, very slightly compact. B_1-horizon	0	3
4.	Loam, buff, sandy, pebbly, slightly compact. B_2-horizon	0	7
5.	Sand, buff, very fine-grained, well-sorted, silty, pebbly	1	0
6.	Gravel, fine-grained, poorly-sorted, in a matrix of medium- to coarse-grained, buff sand. Has gradational contact with horizons 5 and 7	2	0
7.	Gravel, fine-grained, poorly-sorted, in matrix of medium-grained, grayish-brown sand. Oxidized, leached. Sharp contact with horizon 8	2	11
8.	Sand, grayish-brown, medium- to coarse-grained pebbly. Oxidized, leached. Contains yellowish-brown ochre pebbles	1	0
9.	Sand, light-gray, medium-grained, well-sorted, unoxidized, non-calcareous	1	3
10.	Sand, medium- to coarse-grained, light-gray, pebbly, non-calcareous	1	6
11.	Gravel, medium-grained, poorly-sorted in a matrix of medium-grained, buff, silty sand	0	8
12.	Sand, brown with pinkish cast, very fine-grained, compact, silty, pebble-free, oxidized, non-calcareous	0	10
13.	Gravel, medium- to coarse-grained, in a matrix of poorly-sorted brown sand, oxidized, non-calcareous	10	0
14.	Covered to water level in floor of pit	4	0
	Total	26	9

sand. The contact between these two contrasting deposits, shown in Figure 26 (p. 169) is irregular, as though the lower Olean gravel had been subjected to an episode of channel erosion prior to the deposition of the upper Binghamton sand. The lower Olean gravel is completely leached of calcium carbonate whereas the upper Binghamton gravel is calcareous in places.

If the upper sand and gravel is Binghamton in age, the lower Olean outwash gravel must have been deposited during a pre-Binghamton glacial sub-stage. Because it is not rubified, it is supposed that it was laid down after the post-Illinoian episode of rubification and is therefore Olean in age.

In the vicinity of Bristol and Croydon, Pennsylvania, the appearance of the Olean gravel is slightly different from that at Wheat Sheaf. The most notable lithologic difference is a distinct increase seaward in quartz pebbles (Table 35, p. 168). This is the result of the mixing of local gravel deposits, largely of Pensauken age, with the Olean outwash, causing the Olean outwash to become more yellowish in appearance as it is traced seaward. This mixing of gravels downstream has rendered the gravels of Olean age lithologically indistinguishable at some places from the Pensauken gravels.

Binghamton Sand Outwash

The Binghamton outwash deposits consist of gray, medium- to fine-grained, sandy gravel and lenses of gray sand. They are nearly free from interstitial silt and clay and are much less compact than the older deposits. Throughout the Delaware Valley the Binghamton sand was found to be calcareous, though, as may be seen from Table 36 (p. 171), the proportion of calcareous pebbles ranges from nearly 40 percent near Riegelsville to insignificant quantities below Morrisville. Throughout this distance the Binghamton gravels are leached of lime to a depth of eleven feet.

The upper gray sandy gravel in the Tullytown Sand and Gravel Company pit (Figure 26, p. 169) is thought to be of Binghamton age because at places where this deposit fills old channels, secondary calcite and small calcareous pebbles may be found sparsely scattered throughout the gravels at a depth of about eleven feet. This deposit lies upon a higher and therefore older terrace level than the younger gravels of Valley Heads age (Figure 26, p. 169).

Valley Heads Gravel Outwash

The Valley Heads gravels do not differ lithologically from the Binghamton gravels. However, in the Morrisville area, they do appear to be slightly finer-grained and better sorted. They are distinguished from older gravels by a shallower depth of leaching and oxidation—about six feet.

TABLE 38. *Stratigraphic section of Dunnan and Good gravel pit at Upper Black Eddy*

Horizon	*Description*	*Thickness*	
		Feet	*Inches*
1.	Silt, buff, loose, friable, pebble-free	0	2
2.	Sand, buff, very fine-grained, loose, friable	0	5
3.	Silt, dark-buff, compact, even-grained	0	2
4.	Sand, dark-buff, slightly more compact than horizon 2, well sorted, very fine-grained	0	5
5.	Silt, dark-buff, very fine-grained clayey, lower inch mottled with black carbonaceous spots	0	2
6.	Silt, dark gray to dark brown, sandy, loose, friable, stony. Contains pebbles and small cobbles ½ inch to 3 inches in diameter. Buried A-horizon	0	7
7.	Silt, buff, sandy with large proportion of poorly-sorted sand in the matrix. Contains numerous pebbles and small cobbles. B-horizon	1	1
8.	Gravel, buff to light brown, medium-grained, well-sorted, a poorly-sorted sand matrix, oxidized, leached	5	0
9.	Gravel, light-gray to gray, pebbly, in a poorly-sorted sand matrix, unoxidized, non-calcareous, but contains some incompletely weathered dolomite pebbles	4	9
10.	Gravel, gray, pebbly, well-sorted with scattered boulders 3 to 5 feet in maximum diameter. Matrix poorly-sorted, medium- to coarse-grained sand, unoxidized, calcareous	6	0
	Total	18	9

In the northeastern part of Bucks County the occurrence of Valley Heads gravel in valley-train terraces is well illustrated by the stratigraphic section in the Dunnan and Good pit at Upper Black Eddy described in Table 38, (p. 173). Here is a deposit of pebbly, boulder-bearing, sandy gravel is overlain by a thin deposit of sandy silt. Leaching has progressed to a depth of six feet below the top of the gravel. This surface deposit is interpreted as the product of the superposition of flood-plain silts over the Valley Heads gravels laid down in a laterally-shifting stream channel.

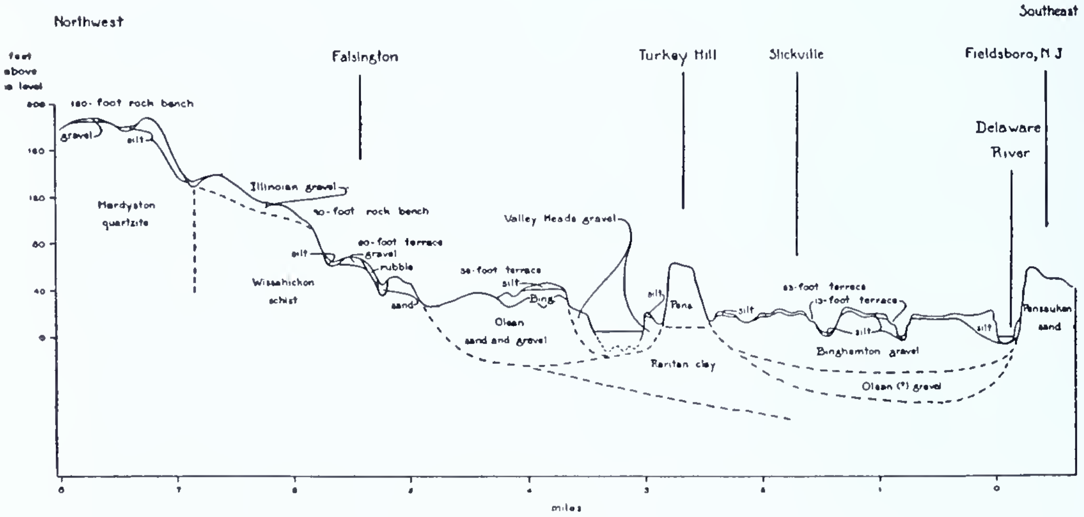
Fine-grained alluvial material similar to that found at the top of this pit overlies Valley Heads gravels throughout the Delaware Valley. It will be discussed below in connection with the post-Valley Heads deposits.

About 36 miles downstream from Upper Black Eddy the Valley Heads gravel is distinctly different in both sorting and coarseness. In the Warner Companys' pit near Morrisville (Table 39, p. 175) the Valley Heads gravel is well-sorted and is overlain by a thin deposit of medium- to fine-grained, well-sorted sand. The Valley Heads gravel is leached to a depth of seven feet below the surface or four and one-half feet below the top of the gravel.

Post-Valley Heads Deposits

The post-Valley Heads deposits (Figures 24, p. 163, 25, p165, and 29, p. 175) consist of silt, sand, and muck laid down during interstadial and/or post-glacial times under conditions of moderate alluviation and relatively quiet waters. The deposits are divisible into three groups, and it is likely that the two youngest, perhaps all three, were separated by episodes of erosion. The three groups are: 1) a thin-bedded, brown silt alternating with gray, very fine-grained sand that forms a

FIGURE 28



Geologic cross section of the Delaware River estuary near Falsington showing the relationship of the several gravel deposits and terrace surfaces.

terrace about 23 feet above present sea level; 2) a similar deposit in terraces about 13 feet above present sea level; and 3) silt and carbonaceous silt or muck now being deposited in submerged channels.

TABLE 39. *Stratigraphic section of exposure in the northern end of the Warner Brothers' gravel pit two miles south of Morrisville*

Horizon	*Description*	*Thickness* *Feet*	*Inches*
1.	Sand, dark-brown, silty, loose, friable, carbonaceous. A-horizon	0	6
2.	Sand, light-brown, silty, slightly compact. B-horizon	0	4
3.	Sand, light-brown, medium- to fine-grained, well-sorted, loose, oxidized	1	10
4.	Gravel, fine-grained, well-sorted, in matrix of medium-grained sand. Leached, oxidized	4	6
5.	Gravel, well-sorted, in matrix of medium-grained sand, calcareous with pebbles of blue, cherty limestone and gray dolomite, and with secondary calcite on pebbles, unoxidized. Exposed to water level	17	0
	Total	24	2

The highest of the post-Valley Heads deposits are well-exposed in the bank of the Delaware River estuary on the Starkey Farm four and one-half miles southeast of Morrisville (Figure 25, p. 165). Here a deposit of structureless silt about two feet thick is underlain by layers of dark-brown to pinkish-brown, well-sorted, laminated silt about two inches thick, separated by beds of tan-colored, very fine-grained, well-sorted sand six inches thick. These deposits must represent quiet-water deposition during an episode of moderate alluviation such as probably prevailed during interstadial time. Possibly these silts and sands are

FIGURE 29

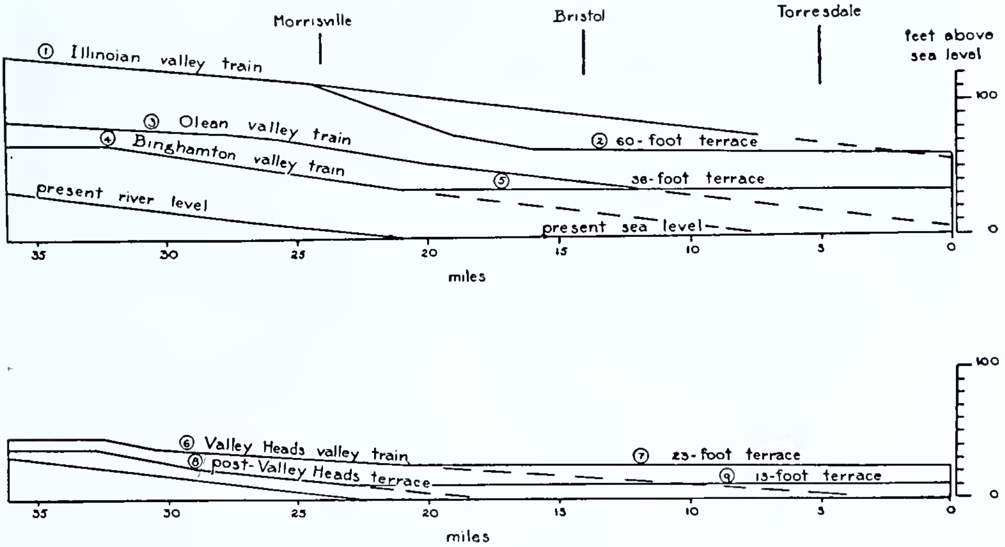


Diagram of the alluvial fan deposits near Morrisville showing the origin of the estuary terraces.

part of a deltaic deposit laid down under conditions of a slightly higher sea level than now prevails.

The deposits of silt and sand in the 13-foot terrace are so similar to those of the higher terrace that the two terraces must be distinguished by their elevation and geomorphic relationships (Figure 27, p. 170). The slope between these two surfaces is so sharply broken in the Morrisville-Bristol area that it must be supposed that they were formed as a result of separate episodes in the geomorphic history.

The 13-foot terrace is now dissected by the waves of the estuary. Adjacent to this terrace and incised into it are abandoned stream channels, now submerged by the tide. In these channels are being deposited organic matter, silt derived from slope wash, and, along the Delaware River, silt mixed with culm. These are the youngest deposits in the southern part of Bucks County and, wherever coal dust and industrial wastes are present, provide a clear datum representing historic times to which Pleistocene stratigraphy may be related.

The present Delaware River channel is covered with a mantle of coarse alluvium consisting mostly of large pebbles, cobblestones, and some boulders. This material is a lag gravel derived from outwash materials, frost-disturbed rubble from valley walls and outcrops in the stream bed. The gravel occurs in the stream bed throughout the Delaware Valley, but it is most conspicuous above Morrisville and is particularly well exhibited near Washington Crossing. Downstream from Morrisville, where subjected to tidal influence, the Delaware River bottom contains similar mantle, but near the center of the channel it is covered by muck, silt and culm.

PLEISTOCENE TERRACES

General Statement

The Pleistocene terraces of the Delaware River (Figures 24, p. 163 and 25, p. 165) are divisible into two groups depending upon their location and condition of formation. The first group, here called valley terraces, comprises those which lie along the relatively narrow part of the Delaware Valley between Riegelsville and Morrisville. The second group comprises those terraces which lie along the broad valley of the Delaware River estuary between Morrisville and Andalusia. The valley terraces are remnants of valley fill deposits, valley trains, and frontal kames derived from the melt-waters of glacial ice which stood in the Delaware Water Gap region. The second group of terraces, on the other hand, consist of broad alluvial fan deposits developed at points where the Delaware Valley widens abruptly. The surfaces of these alluvial deposits are cut by channels or buried by younger alluvial fan, slack water, or deltaic deposits.

Valley Terraces

Four Pleistocene valley train terraces, and terraces in which valley-train material was mixed with periglacial rubble, have been recognized along the Delaware River above Morrisville. They are shown in Figures 24 and 29 (p. 163 and 175). A more detailed study would doubtless yield evidence of other, older valley trains or periglacial gravel deposits. The terraces, remnants of which have been recognized, are: 120-140 foot terrace, the 60 foot terrace, the 40 foot terrace, and the 20 foot terrace. In addition to these principal terraces there exist narrow benches covered with sand and culm which are partly, if not entirely, the product of recent alluviation. These small terraces lie about 10 feet above the river.

Heights of these terraces may vary 10 or more feet from the listed averages but are closer to the figures cited. The greatest variations from average elevations of terraces occur in the northern part of Bucks County where the frontal kames of the two glacial sub-stages have extended downstream from terminal moraines near Belvidere, New Jersey.

120-140 foot Terrace

The highest glaciofluvial deposits in the county form terraces 120-140 feet above the Delaware River. As remnants of this terrace are few in number and poorly preserved, the grade line of this terrace shown in Figure 24 (p. 163) is conjectural. At most localities, these terraces are made up of rubified gravel enclosed in red clayey sand or buff silt matrix. On the basis of weathering characteristics, height above the river, and composition of materials comprising them, these terraces are judged to be Illinoian in age.

The 60-foot Terrace

Remnants of the 60-foot Olean terrace are almost as scarce as those of Illinoian age. They are particularly difficult to find in the northern part of Bucks County and adjacent regions. Within fifteen miles of Morrisville there are pebbly to cobbly gravel deposits that are dirty, poorly sorted, and deeply leached. They are not rubified and lie about 80 feet below the level of known Illinoian deposits in this region (Figure 24, p. 163). They lie about 15 feet higher and appear more deeply oxidized than deposits comprising the 40-foot terrace. On the basis of their lack of rubification, degree of oxidation and leaching, and relationship to Binghamton and Valley Heads deposits, the writer believes this terrace to be of Wisconsin age, formed during the Olean substage.

At the foot of Goat Hill, two miles south of Lambertville, New Jersey, on the left bank of the Delaware River, a good exposure of the gravel comprising this terrace is exposed in an abandoned gravel pit (Table 40, p. 179). Beneath a veneer of slope wash is a deposit of alluvial silt four feet thick underlain by gravel. The surficial layer of silt has been modified to congeliturbate.

The 40-foot Terrace

A series of terrace remnants of Binghamton age standing about 40 feet above the river are more numerous and better preserved than remnants of older higher terraces. A large remnant of what is probably a frontal kame extending downstream from the ice-front position near Belvidere, New Jersey, lies in a rock-defended position on the right bank of the Delaware River above the town of Riegelsville (Table 41, p. 180). Another remnant with a similar position occurs on the northeast side of Coffman Hill at Narrowsville, five miles downstream from Riegelsville. Other conspicuous remnants of this terrace occur 10 miles downstream from Riegelsville.

From Erwinna southward to Raven Rock, New Jersey, a distance of nine miles, the Delaware River flows through a narrow, steep-sided valley cut in the Lockatong and Brunswick Lithofacies. Alluvial deposits of any kind are few and small in this stretch of the Delaware River. No alluvium older than the 25-foot outwash has been found.

At Raven Rock, however, about 45 feet above the Delaware River, there is a deposit of valley train gravel leached to a depth of about 13 feet. As this deposit most closely resembles other remnants comprising the 40-foot terrace in coarseness, weathering, and vertical relationship to other terraces, it is correlated with remnants of the 40-foot terrace upstream from Erwinna.

Remnants of the 40-foot terrace are large and well preserved along the Delaware River for ten miles between Stockton, New Jersey, and Washington Crossing. In this distance (Figure 25, p. 165) two large terrace remnants, which reach 1500 to 3000 feet in width, predominate. Both lie along the right bank, in relatively protected positions on the inside of minor bends in the river. One is between New Hope, Pennsylvania, and Stockton, New Jersey, the other is between Bowman Hill and Washington Crossing. Lesser terraces occur along the left bank at Lambertville, New Jersey, and opposite Brownsburg.

The tops of these large terraces stand between 35 and 45 feet above the Delaware River and have a surface relief of five to ten feet. Their topography consists essentially of a major swale or fosse extending along the foot of the valley wall, with bars in the center and on the riverward side of the terrace. Lesser channelways occupy the bars to modify them and give them a "wash-board" surface. The main channelway probably formed while the alluvium of the terrace was being deposited and while water overflowed the terrace and impinged against the valley wall. The occurrence of a major fosse at the junction between an alluvial plain and the rock wall of a valley has been illustrated by the laboratory experiments of Lewis (1944). Under such conditions of overbank flow a zone of increased turbulence will usually form along the foot of the rock wall, concentrating channel scour at this point, an action illustrated and explained by Leighly (1934) and others. Consequently, the fosse will generally form next to the valley wall and the bar on the riverward side of the terrace.

The writer correlates development of this terrace with the Binghamton substage of the Wisconsin glacial stage recognized in southern New York State.

The 20-foot Terrace

The 20-foot terrace is well-preserved and nearly continuous from Riegelsville to Morrisville (Figure 25, p. 165). In the northeastern part of Bucks County, between Riegelsville and Uhlerstown, a point about ten miles south, there is a higher frontal kame terrace parallel to the 20-foot terrace. Near Milford, New Jersey, this frontal kame begins to decrease in height downstream and finally merges with the valley-train terrace near Uhlerstown. The writer interprets these terraces as having been formed during the Valley Heads substage of the Wisconsin glacial stage.

TABLE 40. *Stratigraphic section in gravel pit on the south flank of Goat Hill, two miles south of Lambertville, New Jersey*

Horizon	*Description*	*Thickness*	
		Feet	*Inches*
1.	Silt, dark-gray, loose, friable, contains scattered fragments of rock 1 to 1½ inches in maximum diameter. A_1 – horizon of modern soil, probably derived from weathering of slope wash . .	0	8
2.	Silt, ash-gray, loose, friable, contains numerous small rock fragments, many of which have become weathered to ochre. B – horizon	0	6
3.	Congeliturbate, brown, stony, silty, compact	2	7
4.	Silt, light-brown to grayish-brown and brown with purplish cast, darker and clayey along the joints, mottled, compact. Contains scattered rock fragments probably derived by mixing with congeliturbate	1	0
5.	Silt, yellowish-brown and light-gray, mottled. Contains purplish clay along joints	0	9
6.	Sand, light-brown, fine-grained, well-sorted	0	2
7.	Sand, purplish-brown, fine-grained, clayey	0	1
8.	Sand, light-gray, purplish-brown mottling, very fine-grained . . .	2	0
9.	Sand, yellowish-brown, very fine-grained, silty, iron-stained . . .	0	10
10.	Gravel, granule size, cemented by black limonite	0	0.5
11.	Gravel, brown, pebbly, in matrix of poorly-sorted pebbly silt . .	2	0
12.	Gravel, brown, pebbly, largely obscured by talus	23	0
13.	Sand, medium-grained, contains scattered pebbles	2	6
	Total	36	1

The 60-foot terrace is characterized by well-sorted gravel in a sandy matrix, covered by between one and five feet of buff, well-sorted sand. The change in sedimentary facies in these terraces must represent a change in the regimen of the Delaware River. The Delaware River today, in time of flood, carries and deposits fine-grained sand and silt. The superficial deposits lying upon the Valley Heads terraces are, then, more comparable to modern deposits than to the deposits of the Valley Heads glacial sub-stage. For this reason the surface veneer of sand on the Valley Heads terrace is interpreted as an interstadial deposit, possibly of Two Creeks age.

Post-Valley Heads Terraces

In addition to the presence of the thin veneer of post-Valley Heads sand covering the gravel deposits of the Valley Heads terraces, there is some further indication in river-bank exposures between Bowman Hill and Morrisville that, in post-Valley Heads time, the gravel was eroded nearly to the present level. These exposures show that after such an episode of erosion, and before the stream became laden with industrial wastes and culm, a deposit of buff-colored, fine-grained sand and silt, up to ten feet in thickness, was laid down. This fine-grained deposit may correspond to or may be younger than the post-Valley Heads sands described above.

PERIGLACIAL DEPOSITS

The periglacial deposits in Bucks County consist of bodies of frost-shattered and frost-disturbed rubble (congeliturbate*), accumulations of angular frost-shattered rock fragments (congelifractate), block fields, involutions, loess and wind-borne sand veneer, dunes, and terraces of poorly-sorted gravel and rubble. The rubble is often recognized by its surface expression as stony, boulder-strewn slopes. The congelifractate may, in a few places, be found as small patches of angular rock fragments, but typically these fragments are mixed either with the products of chemical disintegration of the rock or with wind-borne deposits of sand or silt. The periglacial terraces are the remnants of a once-continuous valley fill of congeliturbate. When compared to glacial outwash this fill is notably angular, dirty and poorly sorted.

The deposits of dune sand and loess were laid down by the relatively strong winds which undoubtedly prevailed in the area during glacial episodes. The close proximity of a body of ice near the sea led to development of strong atmospheric pressure gradients and resulted in winds which blew across the flood-plains of streams which were choked with glacial outwash and periglacial rubble. Because of the severe climate and rapid rate of valley filling, these flood-plains were unprotected from wind scour by an effective cover of plants. The sediments deposited by these winds formed, in the writer's opinion, the sand and silt deposits found extensively in the area south of Morrisville and at scattered localities elsewhere in Bucks County. One small sand dune was identified in a shallow swale 3 miles northwest of Tullytown. However, such occurrences are rare in Bucks County, for most dunes occur on the left bank of the Delaware River estuary (Figure 25, p. 165). It is difficult, however, if not impossible, to determine whether a massive, structureless silt was deposited by wind or by water, particularly when the sediment might have been initially derived from eolian sources.

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* Frost-action terms are taken from "Cryopedology" by Kirk Bryan (1946).

TABLE 41. *Terraces of the Delaware Valley*

Place	*Miles above Morrisville*	*Terrace*	*Bank*	*Height above river*
Riegelsville	41	Illinoian	right	121 feet
		Binghamton (?)		56
		V.H.* frontal kame		35
		Valley Heads		25
		recent		11
Monroe, N. J.	40	V.H. frontal kame	left	33
		Valley Heads		20
Holland, N. J.	38	Binghamton (?)	left	60
		V.H. frontal kame		29
	37	V.H. frontal kame	right	47
		Valley Heads		19
		recent		10
Upper Black Eddy	35	V.H. frontal kame	right	42
		Valley Heads		25
Milford, N. J.	34	Valley Heads	right	27
Lodi	33	Valley Heads	right	28
	32	Valley Heads	right	24
Frenchtown, N. J.	31	Valley Heads	right	22
		recent		10
		Binghamton	left	45
		Valley Heads		25
		recent		15
Erwinna	30	Binghamton	left	40
		Valley Heads	right	18
Smithtown	26	Valley Heads	right	15
Point Pleasant	23	Valley Heads	right	22
		recent		10
Raven Rock, N. J.	21	Illinoian	left	140
		Binghamton		46
		Valley Heads		24
Stockton, N. J.	18.5	Valley Heads	left	25

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* = Valley Heads.

TABLE 41. *Terraces of the Delaware Valley—Continued*

Place	*Miles above Morrisville*	*Terrace*	*Bank*	*Height above river*
Brockville	18	Binghamton	right	47 feet
		Valley Heads		35
		recent		15
New Hope	16	Binghamton	right	35 feet
		Valley Heads		19
Lambertville	16.5	Binghamton	left	43
		Valley Heads		21
		recent		6
Lambertville	15	Binghamton	left	31
		recent		10
New Hope	15	Valley Heads	right	16
Goat Hill	13.5	Olean	left	58
		Binghamton		39
		Valley Heads		26
		recent		9
Bowman Hill	13	Illinoian	right	138
		Binghamton		33
		recent		7
Brownsburg	11.5	Olean	right	56
		Binghamton		40
		Valley Heads		15
Baldpate Mtn.	10	Olean	left	56
		Valley Heads		20
		recent		11
Titusville	9.5	Binghamton	right	45
		Valley Heads		21
Washington Crossing	8	Valley Heads	right	30
		recent		15
Somerset	7	Valley Heads	right	17
		Valley Heads bar		21
Scudders Falls	5.5	Valley Heads	right	22
		recent		7

Periglacial terraces or undissected accumulations of periglacial valley fill, occur in all of the valleys of Bucks County except the Delaware Valley, which was filled with glacial outwash. The material found in the periglacial terraces is generally poorly sorted with large admixtures of clay. However, depending upon the volume of the stream and the distance the deposit lies from the valley wall which was its source, the material may be relatively coarse-grained and rounded or it may be silty, unsorted, and composed predominantly of angular fragments.

Frost action is demonstrated by a soil involution at Croydon, congeliturbate deposits including boulder-strewn slopes, and by block fields, notably the one called Ringing Rocks. The Croydon gravel pit described in Table 42 (p. 182) is the only locality displaying well-developed soil involutions (frost heaving) in Bucks County. The sand and gravel beds of horizons 6 to 9 are here generally contorted and, in the southwest corner of the pit, one large involution in the shape of an asymmetrical cone about 4 feet high and 5 feet wide at the base was observed.

The most common type of frost feature in Bucks County is congeliturbate, characterized by the boulder-strewn slopes most prominently developed below the faces of massive rock such as the diabase. Such boulder-strewn slopes may be seen near New Hope, Point Pleasant, and Quakertown. The development of this type of deposit has been described in detail (Peltier, 1949, p. 64). In essence it is supposed that freezing and thawing served to shatter the rocks of the hillsides and hilltops. The expanding force of the freezing water in this rubble, possibly aided by the downward creep of the weakened, saturated mass during episodes of thaw, produced a downhill movement of the frost-shattered rubble. In Bucks County these deposits are generally 2 to 4 feet thick and distinctly thinner and less impressive than those to be found either nearer the headwaters of the Delaware River or along the Susquehanna River.

Ringing Rocks

Ringing Rocks is a surface accumulation of more or less angular boulders on the northern edge of the Coffman Hill sheet upstream from Upper Black Eddy. It has been mentioned by Miller (1939b) and Ashley (1933). A block field similar to those described by the writer (1949) in the Susquehanna Valley, the boulders and Ringing Rocks consist entirely of Triassic diabase and were probably derived from a single ledge near or directly beneath the field.

The barren, treeless form of the block field is the result of a special

TABLE 42. *Stratigraphic section in gravel pit one mile east of Croydon*

Horizon	*Description*	*Thickness*	
		Feet	*Inches*
1.	Grass roots, partially decayed	0	0.5
2.	Silt loam, dark gray, loose, friable, carbonaceous. This horizon contains closely spaced, horizontal joints which are possibly the result of expansion and contraction of the silt brought about by wetting and drying. A_1 – horizon	0	2
3.	Silt loam, dark buff or brownish-buff, compact, but less so than horizon 4	0	5
4.	Silt loam, dark buff, loess-like, slightly sandy, compact. Contains scattered pebbles. Irregular contact with horizon 5	0	10
5.	Cobblestone band. Consists of cobbles 3 to 6 inches in diameter in a layer one cobble in thickness and with numerous pebbles lying within the same horizon. Interpreted as representing accumulation of coarse lag material resulting from removal of the fine-grained constituents of the Olean deposits during exposure prior to the deposition of the silt loam	0	4
6.	Sand, dark brown, very coarse-grained poorly sorted, containing fine sand and small pebbles, few large pebbles and cobbles present. The base is well-defined and rests upon a contorted bed of sand whose surface has a local relief of 3 inches. Contortion attributed to frost heaving	0	12-15
7.	Sand, buff, fine-grained, well-sorted except for a very few pebbles scattered throughout. Contorted by frost heaving. Sharp contact with horizon 8	0	5-9
8.	Gravel, poorly sorted, in matrix of poorly sorted, compact, fine-grained sand. Contorted	0	7-24
9.	Sand, light-brown, medium-grained, well-sorted. The top of this horizon appears to be contorted, but the base is horizontal	0	12-24
10.	Gravel, poorly sorted, in matrix of coarse-grained sand	1	0
11.	Covered to base	4	0
	Total	12	2

set of circumstances which occurred during or after fragmentation of bed rock and led to the removal of the small pieces of rock and soil particles from between the boulders. The boulders at Ringing Rocks, because of their position in a small, shallow drainage-way, were washed by running melt water which flowed as slope wash over the rubble covered surface. Continuation of this action must have led to the selective removal of particles which the water was competent to transport. Particles small enough to be lifted or tumbled by tiny streams and also small enough to pass through the openings between the boulders were removed. This stage in the history of Ringing Rocks is attested by serrate ridges and furrowed sides on the surfaces of scattered boulders and small pits and pot holes, two to eight inches in diameter and one to four inches deep. The absence of the interstitial soil which would retain enough water to freeze and shatter the boulders, also supports this hypothesis.

LATE PLEISTOCENE HISTORY

Evidence concerning this region during Nebraskan and Kansan time is inadequate to reconstruct the early Pleistocene history. At some pre-Illinoian time, conditions similar to a more recent periglacial environment led to the deposition of the older gravels found at scattered places above the Illinoian grade line. These gravels were possibly related to the Jerseyan glaciations recognized in the Delaware River watershed in New Jersey (Salisbury, 1902; Leverett, 1934; and MacClintock, 1940). There is no reason to suppose that these glaciations are not represented in Pennsylvania, but the scattered masses of gravel and other periglacial features may be the only available evidence.

Illinoian ice extended into northeastern Bucks County near Riegelsville. The outwash from this ice was swept down the Delaware Valley at a level now about 140 feet above the Delaware River. At Morrisville this sediment spread out as a large alluvial fan which had a gradient of about two or three feet per mile and extended at least as far as Philadelphia (Figure 29, p. 175).

The following interglacial interval was one of mild climate. Intense weathering of all exposed rock and soil took place, producing the characteristic red color or rubification of the Illinoian deposits. About the same time, a broad, deep channel was cut in these deposits to a grade within at least twenty feet of the present channel bottom. The Pensauken gravels laid down in this eroded channel and exposed in Turkey Hill are periglacial. Evidence is not available to determine whether these Pensauken gravels represent a separate episode of cold and periglacial conditions in pre-Wisconsin time or are merely a facies of the Olean deposits carried into the Delaware Valley from the east.

The Olean deposits, like the Illinoian, formed an alluvial fan extending seaward from Morrisville, and were deposited within the channelway or valley eroded during a post-Illinoian warm period.

An episode of erosion followed the deposition of the Olean gravel. Channelways such as that exposed at Wheat Sheaf were formed. This erosion must have scoured the Olean deposits to within at least twenty feet of present sea level. In other words, the Olean alluvial fan was dissected to a depth of at least forty feet.

The Binghamton deposits, swept down the Delaware Valley from an ice front in the vicinity of Belvidere, New Jersey, north of Bucks County, filled the valley to a depth of about forty feet with sand and gravel. At Morrisville they spread out in an alluvial fan that filled the post-Olean channels and buried most of the Olean gravels. This fan was the smallest of those deposited here, extending no more than six miles down the valley. Beyond this point the Binghamton melt waters flowed within the post-Olean channel below the level of the Olean deposits.

During the post-Binghamton interstadial interval the relatively quiet conditions of stream flow, possibly retarded by a rise in sea level, led to the development of the 36-foot river mouth terraces. Toward the close of this interval an acceleration in the downcutting of the Delaware River formed a channel extending from Trenton, New Jersey, west of Turkey Hill, to Edgely, Pennsylvania. Possibly this accelerated erosion was the result of a lowering of sea level as the cold episode of Valley Heads time approached a climax, but before the glacial ice reached the Delaware River watershed. About the same time the channel of the Delaware River above Morrisville was probably swept clean of the Binghamton outwash deposits.

The Valley Heads deposits, like those of Binghamton age, were carried down the Delaware River from an ice front near Belvidere, New Jersey. The frontal kame of the Belvidere stand extended as far south as Milford, New Jersey. The accompanying episode of alluviation filled the valley to a depth of about 22 feet, but, unlike previous valley train deposits, no alluvial fan formed at Morrisville. The Valley Heads deposits remained restricted to the post-Binghamton channel and continued seaward, apparently never rising above the surface of preexisting deposits.

The Valley Heads episode was followed by a rise in sea level and the development of 23-foot river mouth terraces, accompanied by deposition of alluvial sand upon the Valley Heads valley train terrace along the Delaware River and alluvial sand and silt over and against the 23-foot terrace. This interstadial interval can probably be correlated with the Two Creeks interval in Wisconsin described by Wilson (1932).

There followed, perhaps during Mankato time, an interval of channel scouring which was probably attendant upon the lowering of sea level. No outwash flowed along the Delaware Valley during the Mankato glacial sub-stage. Some alluviation of periglacial gravel may have occurred, but such deposits, if they existed, are now buried beneath younger alluvium of the post-Valley Heads composite terrace.

The youngest Pleistocene surface and associated deposits so far recognized in Bucks County are those of 13-foot river mouth terraces. They can probably be correlated with the Mankato-Cochrane interstadial interval. This episode of high sea level was followed by a brief period during which the channels were cut below present sea level. This is probably to be correlated with the Cochrane stage of Antevs (1922).

The present or recent episode is one characterized by a rise in sea level and a submergence of the Cochrane channels. Muck, silt, sand, and some culm are currently being carried and deposited by the Delaware River.

Chapter VI

MINERAL RESOURCES

by

H. R. Gault

Mineral production in Bucks County consists of sand and gravel, crushed stone, building, ornamental and other dimension stone, lime, ocher, slag, clay and clay products, and silica refractories. There has been production in the past of iron ore, flux rock and cement. Occurrences of lead and zinc, copper, barite, and gold have been prospected.

In the following discussion only slight attention is given to abandoned non-metallic properties. Many non-operating quarries and pits are indicated on the geologic map of Bucks County (Plate 2, in pocket) but no attempt was made to exhaustively locate every opening. The operating plants listed include those which were working continuously or intermittently in the period 1954-1956. Production figures for individual operations are available for most places.

Sand and Gravel

by

H. R. Gault and Joseph H. Goth, Jr.

Sand and gravel are among the most valuable mineral products of Bucks County. The principal uses are for construction purposes in concrete and highway construction. Some goes into "ready-mixed" concrete. Fine-grained sand sizes are used for bricklaying and plastering. Some molding sand has been produced from limited areas, mainly near Tullytown.

The bulk of the sand and gravel production is from the Quaternary deposits in the southeastern part of Bucks County in the Yardley-Morrisville-Tulleytown area. Lesser amounts are or have been produced from terraces and other alluvial deposits along the Delaware River as far north as Riegelsville.

Small sand pits have been operated in other parts of Bucks County for local use, principally in disintegrated sandstone and quartzite beds from the Hardyston Quartzite and Stockton Lithofacies. The Buckingham Mountain area is spotted with old pits in weathered Hardyston Quartzite. Several old pits in Stockton Lithofacies were operated near Doylestown and northwest of Langhorne near Neshaminy Creek. North of Langhorne is a quarry about 30 feet deep in weathered friable sandstone of Stockton Lithofacies.

The outwash terrace and valley train material of the Delaware River are the most important source of sand and gravel in Bucks County. The deposits are characterized by a large variety of rock fragments; types identified include Paleozoic limestone and chert, quartzite, sandstone, Triassic shale, sandstone and diabase, Pre-Cambrian gneiss and granite. The quartzites and sandstones are most abundant. Limestone is common at Riegelsville but absent several miles below New Hope. Triassic shales, sandstones and diabase are found principally below New Hope.

The texture of the gravel deposits is relatively uniform. Pebbles one to four inches in diameter are common; cobbles five to nine inches are abundant and, in places, boulders several feet in diameter are recovered. Although the cobbles and boulders are not well rounded, the smaller-sized gravels are well worn.

The thickness of gravel deposits ranges from 14 to 50 feet. In the Morrisville area it averages about 30 feet. A generalized section of the Riegelsville pit (Table 43, p. 186) was measured by Ward (1941).

TABLE 43. *Generalized section, Riegelsville pit*

	Thickness in feet
Pebbly gravel with some cobbles	1-5
Coarse-grained sand, cross-bedded to south, scattered pebbles and silty beds	6-10
Silt, persistent, somewhat clayey	2-3
Sand with silty beds, thickness variable, underlain by pebbly gravel with some cobbles and boulders, locally cemented	20±

Maximum exposure, 30 feet.

Whether or not a deposit can be worked profitably depends upon a number of factors such as: reserves, demand, market conditions, quality of gravel, and transportation facilities. Sand and gravel are bulky low-cost products, and transportation is an important factor. Railroad and barges can be used profitably only where large quantities are available, and there is an immediate market. Trucking is a common mode of transport, but the market for the gravel must be reasonably close, with 25 miles as a probable maximum limit.

The product must be uniform and pass certain strength, size, and compositional tests. Crushing, screening, and washing equipment are generally necessary. Although dredges are used at the largest operation in Bucks County for excavating (Plate 23, p. 187), other plants use diesel or "gas" shovels. Quarries in bedrock furnishing crushed stone are competitors for the gravel producers.

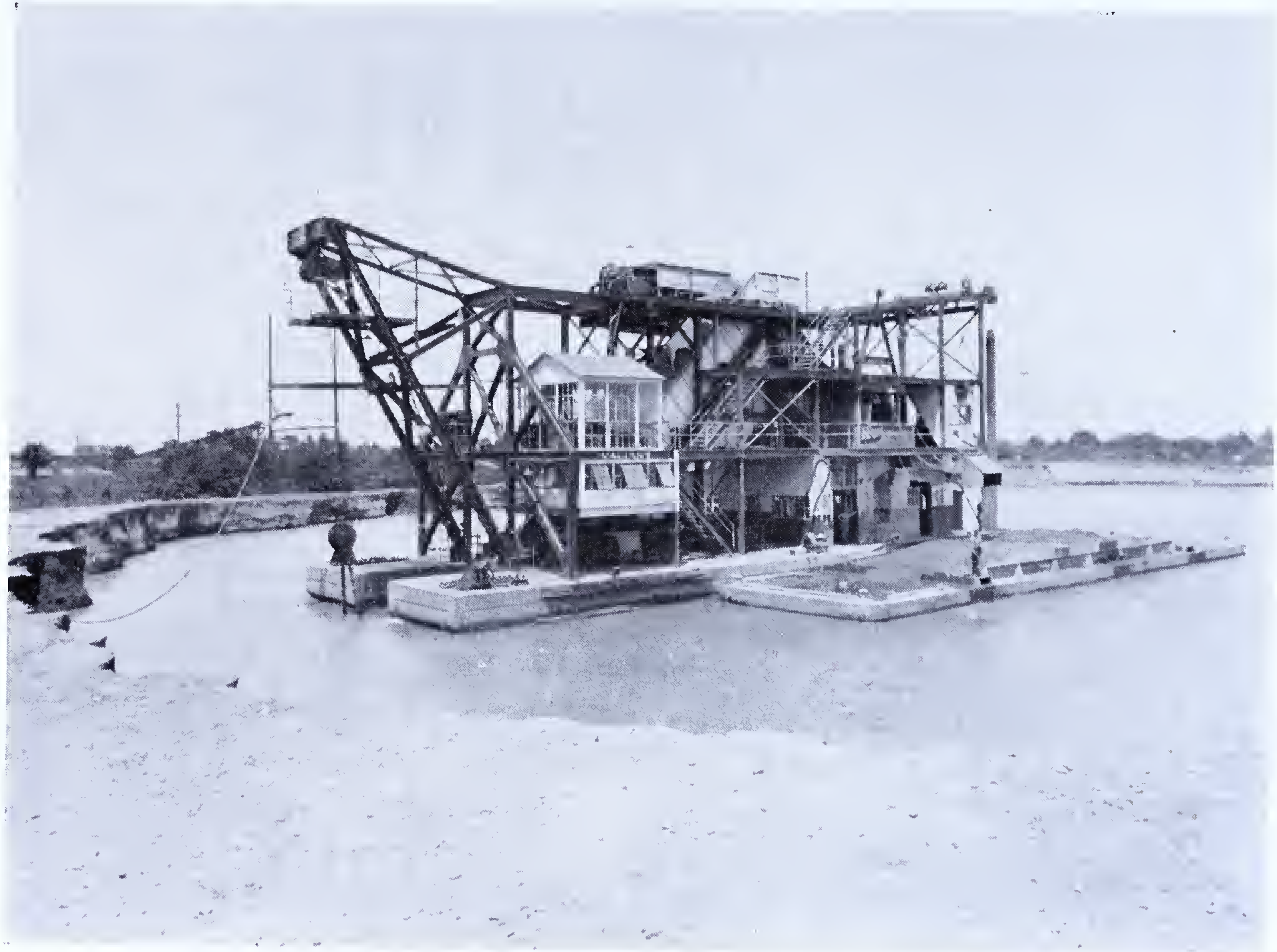
Specifications for aggregate stone

The Pennsylvania Department of Highways (1946) has set up size, strength and compositional specifications for fine and coarse aggregate for concrete and bituminous mixtures of both gravel and crushed stone. A summary of these specifications is given in Table 44 (p. 188) and 45 (p. 188), as they are not readily available in most publications.

Fine aggregate (Table 46, p. 188) is material passing a three-eighths inch mesh sieve. The specifications are for fine aggregate other than that used in bituminous mixtures. They must consist of sand and of approved quality from an approved source, clean and free from lumps of clay and all vegetable and deleterious substances (Table 45, p. 188). It must be composed of hard durable grains and must meet the minimum strength test of sand in mortar compared with Ottawa sand made on test blocks aged for 7 and 28 days. The soundness test consists of five alterations with sodium sulphate solution with the loss not to exceed ten percent. The Pennsylvania Department of Highways supervises the tests and from time to time runs check tests on all approved sources.

Coarse aggregate should be reasonably free from coatings of clay, silt or dust. All materials must meet with minimum physical requirements of Table 44 (p. 188), shall not exceed the maximum compositional allowance of deleterious substances of Table 45 (p. 188), and

PLATE 23



Dredge operating at Warner Company gravel pit.

TABLE 44. *Specifications for aggregate of the Pennsylvania Department of Highways*

Physical Requirements	*Type A*		*Type B*		*Type C*	
	Stone	*Gravel*	*Stone*	*Gravel*	*Stone*	*Gravel*
[1] Deval abrasion test; max. (AASHO method T-3)	5		6		4	
[1] Toughness test; min. (AASHO method T-5)	6		5			
Sodium sulphate test—max.; percentage loss at five cycles by weight (AASHO method T-104)	10	10	10	10		
Los Angeles rattler test—max.; percentage loss by weight						
@ 100 revolutions	10	10	13	13		
@ 500 revolutions	35	35	45	45		
(AASHO method T-96)						
[2] Thin and elongated pieces; percentage by weight max.	5	5	5	5		
[3] Loss by washing; percentage by weight max. (AASHO method T-11)	0·5	0.5	0.75	0.75		
[4] Crushed fragments; min. percentage by weight—individual sizes		45				
percentage by weight—combined sizes		55				

---

[1] Tests required only on samples originating from all undeveloped sources, all new sources, and on commercial sources when directed by the Engineer of Tests.

[2] Determined on materials retained on the 1" square sieve. Flat and elongated particles have an average thickness or depth less than one-fifth of the greatest dimension.

[3] Except that #100 sieve shall be used and sample shall weigh between 50 and 100 pounds.

[4] Artificial crushing of the gravel with substantially all fragments having at least one fracture face. Nicked gravel is not considered crushed.

TABLE 45. *Deleterious substances[1] in aggregate*

	Type A		*Type B*	
	Stone	*Gravel*	*Stone*	*Gravel*
Soft fragments, percentage by weight, max.	2	2	2	2
Shale, percentage by weight, max.	1	1	1	1
Clay lumps, percentage by weight, max.	.25	.25	.25	.25
Coal or coke, percentage by weight, max.		1		1

---

[1] The sum of percentages of all deleterious or objectionable substances exclusive of glassy particles and iron shall not exceed 2 percent for type A and 3 percent for Type B.

must be crushed and screened to meet the size and grading requirements of the mechanical analyses in Table 47 (p. 189).

Types A, B and C, coarse aggregate, are tough durable rock, free from slaty cleavage. Gravel types A and B are hard, tough, durable, and impermeable particles, crushed or uncrushed as required, and thoroughly washed to remove impurities prior to loading.

TABLE 46. *Grading and Quality Requirements for Fine Aggregate*

Percent passing	*Type*			
(Sieve size)	*A*	*B*	*C*	*D*
#100	1-8	1-8	0-10	0-8
#50	10-30	10-30	...	5-30
#20	40-75	40-75	80-100	50-80
#10	..	..	100	..
#4	90-100	90-100	...	100
⅜"	100	100	...	..
Maximum silt percent	30	5	5	5
Maximum strength ratio	90	90	60	..
Soundness test maximum loss in percent	10	10	10	..

TABLE 47. *Size and Grading Requirements for Coarse Aggregates*

Pennsylvania	*Total percentage Passing (Based on Laboratory Sieve Tests, Square Openings)*											
No.	*100*	*8*	*4*	*¼″*	*½″*	*¾″*	*1″*	*1¼″*	*1½″*	*2″*	*2½″*	*3″*	*3½″*
1	10-30			85-100	100								
1B		0-15	10-30		100								
2			0-15		40-60	90-100	100						
2A	5-40						100						
2B			0-10		20-50		90-100	100					
3A							0-15		35-70	90-100	100		
4							0-15			35-70		90-100	100

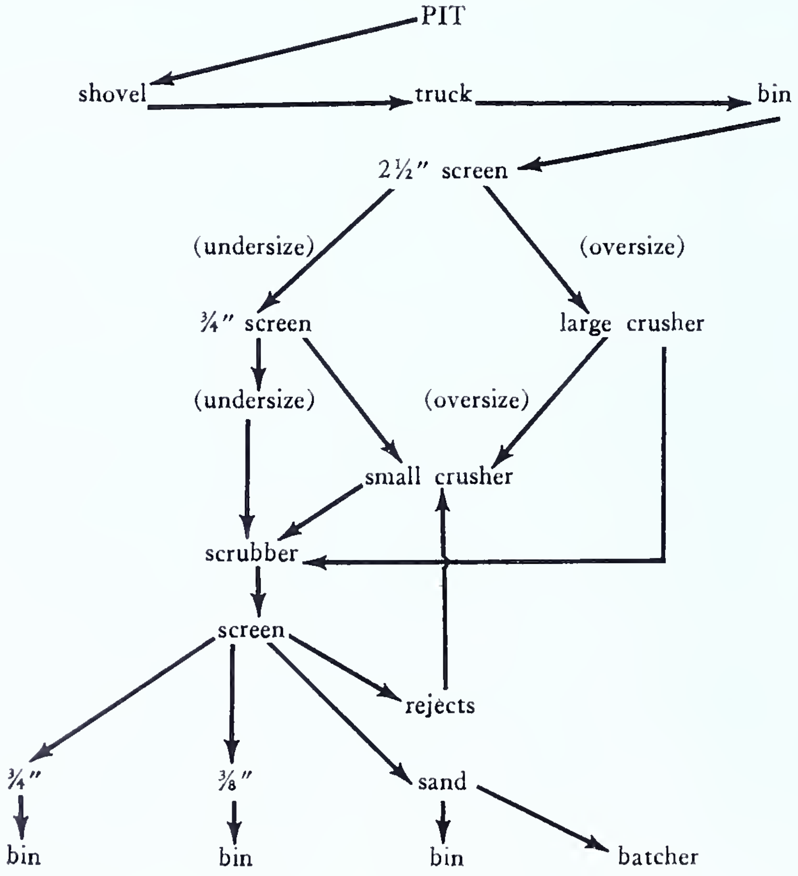
Operating Plants

The Amico Sand and Gravel Company operates two plants, one in south Morrisville and another half a mile west of Penn Valley. The Morrisville plant has operated since 1934; the Penn Valley plant was opened in 1949 and was still in operation in 1955. Excavating is done with a power shovel. The gravel passes through three sets of crushers and is then screened into various sizes. Production for 1955 for all sizes was about 300,000 short tons.

The Brennan Sand Company operates a small sand pit in Tullytown, Pa. Production for 1955 was about 1200 short tons of sand.

The Durnan and Good gravel pit is at Upper Black Eddy. They also have a sand pit 2½ miles south of Upper Black Eddy. The material in the gravel pit is pebbly and contains cobbles up to 8 inches in diameter. The sand pit consists primarily of sand but occasional boulders two feet in diameter are uncovered. Production of sand and gravel during 1955 totaled about 250,000 short tons.

Three grades of material are produced at the gravel pit; 1) sand, (3/16″ is the largest size with about 10 percent passing the 100 mesh sieve); 2) ⅜″ stone, ranging from 3/16″-½″; and 3) ¾″ stone, ranging from ½″-1¼″ (Pennsylvania 2B). Two power shovels, one dragline, and a loader are used in excavating. Gravel is trucked to bins and then processed. A generalized flow sheet of the operations is given below.



A. L. Lewis is operating a sand and gravel pit at New Hope near the site of the old Acme Sand and Gravel Company pit. There has been considerable production in the past as indicated by several old pits now grown over with vegetation. A working face of the new pit showed interbedded pebbly gravels (4 inch cobbles) and sandy lenses 18 to 30 inches thick. The individual lenses, many of which are inclined, pinch out in a short distance. Production of sand and gravel during 1955 totaled about 50,000 short tons.

The Tullytown Sand and Gravel Company pit is 1½ miles north of Tullytown on U. S. 13. The pit has operated since 1923 and produced about 110,000 tons of sand and gravel in 1955. Two power shovels are used to excavate. The gravels go through a jaw crusher and then through a rotary crusher. The crushed material then passes through three sets of revolving screens. Seven types of products are separated:

1. Concrete sand
2. Bar sand
3. Pea gravel
4. ¾ inch gravel
5. 1½ inch gravel
6. Grit
7. 100 percent crushed gravel
    a. Pennsylvania 1B
    b. Pennsylvania 2B
    c. Crusher dust

Warner Company, 219 North Broad St., Philadelphia 7, Pennsylvania, is the largest operator for sand and gravel in Bucks County. Two sites are worked, the Van Sciver plant on an artificial inland lake near Morrisville and a dredging site five-eighths of a mile south of Tullytown at the Delaware River. The Van Sciver site was originally opened in 1917 by James Mundy of the Penn Sand and Gravel Company. The Van Sciver Company took over in 1921, and the Warner Company in 1929.

The Warner operation is an excellent illustration of a modern plant for large scale preparation of sand and gravel. The favorable location of such a large deposit of gravel with respect to markets reached by water, rail and truck transport has been of great importance in the development of this large operation. Favorable natural factors alone, however, are not sufficient to guarantee a successful operation. The handling of large tonnages of bulky low-cost products such as sand and gravel raises many problems which require efficient engineering and management. The large tonnages demand heavy equipment units which are costly. The abrasive action of sand and gravel greatly shortens the life of the equipment with frequent replacements needed. Since sand and gravel production is essentially an open-air operation, winter weather makes operation difficult, particularly because of the dredging operations and the large amount of water used in washing and screening.

The volume of road and building construction is subject to seasonal and economic fluctuations, so that the demand for sand and gravel is not constant, even though the production capacity is more or less fixed. The natural gradation in the raw gravel is more or less constant, but the quantity of the various sizes of gravel needed may vary from that of the natural gradation in the ground. Some gravels must be crushed or stored for future use. Another operational problem in the handling of various sizes of gravel is the difference in specification of the several state highway departments and municipal governments. For instance, Pennsylvania 2B gravel is comparable in size distribution to Delaware 105A, but there is a difference in the allowable proportions of crushed particles. The specifications for concrete sand in New Jersey are not the same as those in Pennsylvania. Many other problems are met and must be solved before this or any other operation handling mineral resources can be successful.

The size and complexity of the Warner Company operation is indicated by a listing of their heavy equipment units. They operate two steel dredges (Plate 23, p. 187), a fleet of barges for carrying raw and finished gravel, steel tugs for towing the barges, a standard gauge railroad, and a fleet of trucks for hauling sand, gravel, and central-mix concrete.

The dredge "Valiant" (Plate 23, p. 187) operates on the Van Sciver lake and loads the raw sand and gravel directly into barges, which then are towed to the crushing and screening plant. The dredge "Franklin" at the Delaware River not only digs but washes, crushes and screens the sand and gravel, so that these products can be loaded into barges for immediate trans-shipment to market. The flow sheet of the Van Sciver plant is more complex than in smaller operations, but does not differ in principle. The sand and gravel are unloaded from barges, or from the digging buckets of the dredge, into scalping screens, then to other screens by gravity, belt conveyors, or bucket elevators. Oversize material goes to crushers and then it is rescreened. Undersize goes to scrubbers and other screens and some may go to secondary crushers. The materials continue through the plant until all is properly sized and dewatered. It is then stored in bins or on stockpiles, or is loaded directly into barges or railroad cars for shipment to market.

TABLE 48

Products of the Van Sciver Plant, Morrisville, Pa.

1. Plaster sand
2. Concrete Sand (three grades meeting the specifications of the ASTM, Pennsylvania Department of Highways, 1946, Delaware Highway Department, New Jersey Highway Department, and several city building codes)
3. 1½" Commercial Gravel (Navy 2") (ASTM and Federal #4 to 2")
4. New Jersey Stripped Gravel
5. ¾" Gravel (Navy 1") (ASTM and Federal #4 to 1")
6. Pea gravel (largest size is ½" square opening)
7. Grit (largest size is ⅜")
8. Pennsylvania 1B Crushed Gravel
9. Pennsylvania 2 Crushed Gravel
10. Pennsylvania 2B (1¼" to #4) = 45 percent Crushed Gravel
11. Pennsylvania 3A (2½" to 1") = 45 percent Crushed Gravel
12. Delaware 106 (Same as Pennsylvania 3A) (No crushed requirements)
13. Delaware 106A (Same as Pennsylvania 2B) (No crushed requirements)
14. Cobbles (over 8", for rip-rap, etc.)

Sand and gravel are shipped by water to ports on the Delaware River as far as Wilmington, Delaware, on railroad cars for a radius of 60 to 120 miles, and on trucks in a radius of 15 to 20 miles. The estimated capacity of the Van Sciver plant is about 35,000 tons per week per shift. The combined production of sand and gravel of both plants exceeded 4,000,000 short tons in 1955.

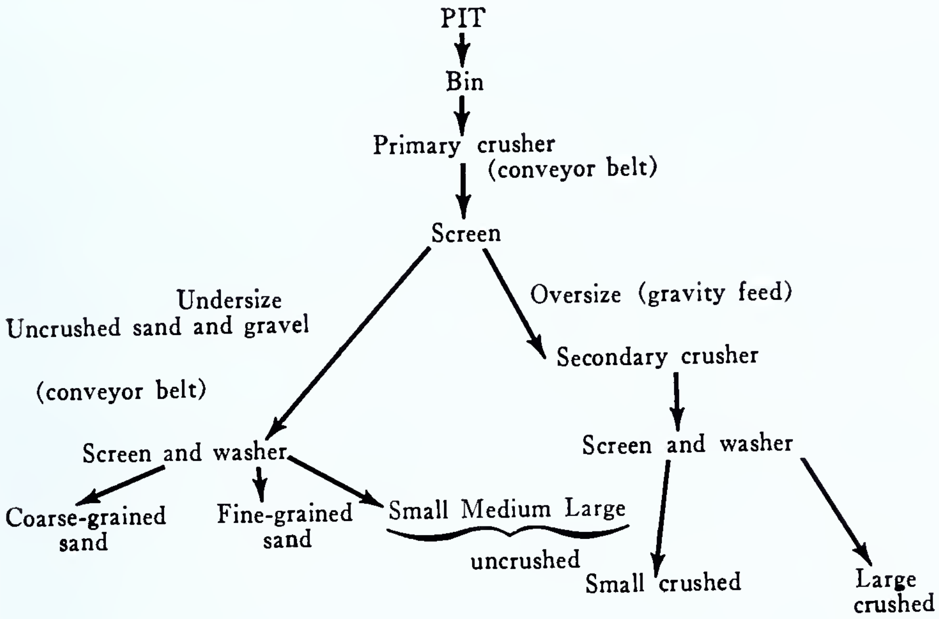
Other Operations

Silvi Sand and Gravel Co. in Tullytown, produced almost 60,000 short tons of sand and gravel during 1955.

Riegelsville Sand and Gravel Company re-opened a large abandoned pit south of Riegelsville and produced about 41,000 short tons of sand and gravel in 1955.

There are many abandoned or worked out sand and gravel pits in the Morrisville-Tullytown area. Individual descriptions are not given as many pits are water-filled, slumped or over-grown with vegetation.

The flow sheet which follows illustrates the general procedure of treating gravels (Ward, 1941).



CRUSHED STONE

The production of crushed stone is an important contribution to the mineral wealth of Bucks County. Many small abandoned pits and quarries scattered throughout Bucks County indicate considerable local usage of crushed stone for construction and road work. The operating plants are generally located within a radius of 20 to 25 miles of the consumer. A few of the larger operations ship ballast and other stone to points out of their immediate neighborhood.

Four types of rock are quarried for crushed stone: 1) Paleozoic limestone, 2) Triassic red or black sandstone, argillite and shale, 3) Triassic gray to black baked shale; and 4) Triassic diabase. Most of these materials will meet the rigid specifications of the Pennsylvania Department of Highways (1946). Some operators, however, have not sought state approval because they can dispose of their stone to other consumers. This does not signify that such stone could not meet these specifications which have been summarized under sand and gravel (Table 44, p. 188 and Table 45, p. 188).

Operating Plants

The Bituminous Service Company operates a large quarry in Paleozoic dolomite about one mile east of Buckingham near the Reading Railroad. All production from this quarry is crushed stone. The dolomite beds dip about 30°NW. and strike about N.65°E.

The rock is blasted down, loaded with power shovels and goes through jaw crushers, respectively 36″ x 30 ″, 36″ x 13″ and 30″ x 10″. After crushing, the stone is sized by two revolving and one vibrator screen. Seven sizes are produced, all meeting Pennsylvania Department of Highway (1946) requirements. Sizes produced are:

Pennsylvania #1
Pennsylvania #1B
Pennsylvania #2 (40 percent ½″)
Pennsylvania #2B (mostly ¾″)
Pennsylvania #3A
Pennsylvania #4
Pennsylvania #4A

Production capacity is estimated as about 250 tons per day, but the plant does not operate during the winter months. In 1955, about 35,000 tons of crushed stone were produced. The bulk of the stone is used for road metal but some of the finer material is mixed with asphalt for black top in an asphalt mixing plant at the quarry.

The D. D. Derstines quarry is about one and three-quarter miles southwest of Sellersville near Perkiomen Creek. The quarry is in red and black Triassic sandstones and sandy shales. The floor of the quarry is a bedding plane surface of red sandstone dipping about 12°N. Reddish sandstone lies near the top of the quarry section, with a dark-gray zone in the middle. The quarry floor, as viewed from the edge of the quarry, appears to have been ruled off by white horizontal lines 2-6 feet apart with diagonal lines between the horizontal lines. The effect, quite marked, is the result of the filling with calcite of vertical fractures trending NE-SW. These veins are one-sixteenth to five-eighths inches wide and are made up of series of long discontinuous lenses. Much of the calcite is fibrous. Small pyrite crystals also occur in the veins. The veins continue up through the lower red beds into the dark-gray beds. Crushed stone is produced at an estimated rate of about 100 tons per day.

The General Crushed Stone Company has a plant on the southern slope of Rock Hill near Quakertown about one-half mile southeast of Rock Hill station on the Reading Railroad. The quarry is in Triassic diabase and is the largest crushed stone operation in Bucks County.

Production is about 250,000 to 300,000 tons per year. Much of the production is used for railroad ballast but all sizes of highway material are produced. There is a siding for loading railroad cars.

Francis Gloster owns and operates a quarry in the Lockatong Lithofacies one mile southwest of Tradesville near the Mill Creek school. The rock in the quarry is a black, tough shale dipping about 7°NW. Some of the beds are thin and well fractured with calcite veins filling some of the fractures. Most of the calcite is granular but some is fibrous. The quarry floor is almost a bedding surface.

The quarry has been in operation since 1924 and until 1941 produced about 28,000 tons per year of crushed stone. Since 1941 production has averaged about 15,000 tons. The rock is blasted from the quarry face and is sent through a 20-inch gyratory crusher. Two revolving screens are used to separate six sizes of stone. The sizes produced are:

Grit — Pennsylvania #1
Pennsylvania #1B
Pennsylvania #2B
Pennsylvania #2
Pennsylvania #3A
Oversize

George Miller and Son operate a quarry in Triassic black argillite south of Doylestown. The operation began in 1949. The rock is blasted from the face, loaded by power shovel into trucks and taken to a bin. The quarry rock goes into a 16 inch x 24 inch jaw crusher and is carried by belt from the crusher to a revolving screen. The production is about 225 tons per day. Products include:

Ballast
1½" stone
¾" stone
½" stone
Screenings
Building stone
Spalls
Topsoil and dirt fill

The J. Magazino and Sons Company produce about 2500 tons of dimension sandstone and crushed sandstone per year.

The New Hope Crushed Stone Company operates a quarry in dolomite of the Conococheague (Limeport) Limestone about 1½ miles northwest of New Hope on the north side of a small creek. A small abandoned quarry immediately west of the New Hope quarry is separated from it by a narrow wall of shattered dolomite and a diabase dike. Another abandoned quarry lies across the small creek.

The beds in the New Hope quarry dip southwest, whereas those in the abandoned quarry across the creek dip northwest indicating a small syncline whose axis is about in the creek. A thickness of about 45 feet of beds is exposed in the New Hope quarry. Chemical analyses of specimens of Conococheague (Limeport) Limestone from the New Hope quarry are given in Table 49: sample 1 from the top of the quarry section and sample 5 at the base. A thickness of about 45 feet of beds are exposed in the quarry across the creek. Chemical analyses of six samples representing a nearly continuous section from top to bottom are given in numbers 6 to 11 in Table 49.

The plant produced about 120,000 tons of crushed rock in 1955. The quarry rock is trucked to the jaw crusher from which it passes through a roll crusher. The crushed stone goes to vibrating screens. All crushed rock after leaving the jaw crusher moves on belt conveyors.

TABLE 49. *Chemical Analyses of Conococheague (Limeport) Limestone from the New Hope quarry*

Sample	*Thickness in feet*	$CaCO_3$	$MgCO_3$	SiO_2	Fe_2O_3	Al_2O_3
1	10	48.09	40.87	7.83	.77	3.15
2	6	52.62	44.18	2.24	.70	.41
3	8	47.74	40.00	8.19	.83	3.58
4	10	52.52	43.63	2.35	.84	1.32
5	10	49.80	41.67	5.53	.98	2.65
6	7	50.74	42.56	4.61	.73	1.44
7	6	52.56	44.00	1.97	1.01	.68
8	5½	51.37	44.81	1.63	.70	.76
9	9	49.49	41.44	6.05	1.08	1.37
10	5½	52.47	44.37	2.18	.80	1.09
11	11	51.26	43.14	3.81	.91	.93

The New Hope quarry produces ⅛″, ⅜″, 1″ and 1½″ crushed stone. The bulk of the production is for black top for roads.

The Plumstead Township quarry, about half a mile southwest of Point Pleasant, is in baked Triassic argillite and furnishes a tough crushed stone. An excellent system of joints has developed in the rock. Some of the rock contains flecks of white cordierite. The township operates the quarry intermittently producing about 3,200 tons per year with a daily capacity of 40 tons. The blasted rock goes to a jaw crusher and thence by bucket chain to a revolving screen. The screen is equipped to separate fine sizes of material with screen openings of 1½, 1¼, and one inch round holes and one-half and one-quarter inch square holes. Some building stone for highway bridges and culverts is also taken from this quarry by the Delaware Quarry Company.

The Tohickon Quarry Company quarry is about two miles west of Richland Center, west of Quakertown. The property consists of 65 acres owned by Clyde Feist. The quarry was opened in 1936 and has produced 10,000-12,000 tons per year with a capacity of 60-80 tons per day. The quarry rock is baked Triassic argillite. Shot holes are put down on a contract basis. The blasted rock goes to a jaw crusher, then to a chain lift (cups) and is sized in a rotary screen. Sizes produced are:

sand
½″
¾″
1½″
ballast
Pennsylvania #2

About 300 tons per year of foundation stone are also produced.

The George Wiley quarry is about one mile southwest of Point Pleasant and half a mile west of the Plumstead Township quarry in the same baked argillite zone as the Plumstead Township quarry. The quarry is about 30 years old and has been used by the present operator since 1941. The bulk of the production goes into driveway and road construction. The capacity of the plant is about 30,000 tons per year but has produced only 10,000-20,000 tons per year.

Blasted stone is loaded into trucks by a shovel and goes through two jaw crushers. A bucket chain takes the crushed stone to a rotary screen. All material over 3½ inches is returned to the second jaw crusher. Tailings from the rotary screen are fed onto a vibrating screen. Five sizes of material are produced: ballast (+3½″), 1½ (3A), ¾ (2B), ½ (1B) and grit screenings.

W. T. Wilkinson operates a quarry near Rushland in Lockatong Lithofacies. The rock is a dark-gray to blue-gray tough argillite or shale. Calcite veins are common and pyrite occurs in much of the rock. Thin-bedded black shale bands are interbedded with massive, thick-bedded, blue-gray rock. These black shale bands appeared to have served as local slippage zones. Some contain fossil fish scales and plant remains.

The quarry was originally opened in 1898 and has been producing crushed stone and a limited amount of foundation stone continuously. The rock is blasted, loaded with diesel shovels into trucks and is crushed in a 30 inch x 13 inch jaw crusher, a gyratory crusher and a roll crusher. After crushing, the stone passes through a 42 inch rotary screen (smallest opening, 1½ inches) and over a vibrating screen. Sizes produced are:

screenings
chips (⅜″)
¾″
1½″
ballast (Pennsylvania #4)

The Yoder quarry is about three-quarters of a mile southeast of Blooming Glen in the Doylestown area. Another small quarry was worked about one-quarter of a mile to the northeast. Both quarries are in Triassic red sandstone and shale of Stockton Lithofacies. The Yoder quarry was opened in 1908 and has operated nearly continuously, although in recent years, at least, it has shut down in the summer months. Most of the stone goes into driveways and township roads but up until 1941 about 10 percent of the production was building stone. Production has averaged about 10,000 tons per year up to 1929, 20,000 tons until 1934, and about 10,000 tons since 1934.

The blasted rock is loaded with power shovels and goes to a jaw crusher. Sizing is done with a rotary screen. The sizes produced include:

sand-grit
¼″
½″
¾″
1½″
3″

BUILDING, ORNAMENTAL, AND OTHER DIMENSION STONE

by

H. R. GAULT AND JOSEPH H. GOTH, JR.

A greater variety of rock types is used for dimension stone than for crushed stone. Triassic diabase, red sandstone (brownstone), dark gray argillite, baked shale and arkose, Chickies and Hardyston Quartzite, Wissahickon Schist, and Baltimore gneiss are used in the production of dimension stone. The bulk of the stone supplies local demands but a few, particularly the diabase, are in wide demand.

A good general discussion of building stones in Pennsylvania and an excellent listing of many of the older homes, mills, inns, and churches built with stone from Bucks County has been prepared by Stone (1932). As Stone has pointed out, many of the older bulidings or their foundations were built from local or field stone, and an approximation of the underlying bedrock can be made by glancing at foundations of houses or barns in Bucks County. With the advent of cement and the concrete block industry, the demand for dimension stone has fallen off. Nevertheless, there is still a considerable production. Some is used for foundation work and some large homes use gneiss for facing. Highway construction takes some production of rough ashlar stones (squared blocks) for culverts and small bridges. Of considerable importance is the use of diabase for precision instrument bases and monuments. Flagstones are obtained from Hardyston Quartzite, Triassic sediments and other rocks. Details of production and use are discussed under the individual operating units.

Pennsylvania State Highway Department Specifications (1946)

Pennsylvania State Highway Department specifications (1946) require that dimension stone used in highway construction must meet certain requirements. A summary of these requirements follows:

Ashlar rubble masonry stones (ashlar blocks are squared blocks) shall be face hammered (rock face ashlar). Ashlar stones shall meet the quality requirements of Type B stone (Table 44, p. 188). Blocks shall be squared not less than 8 inches and not more than 18 inches thick. The width shall not be less than 1¼ times the thickness. Headers shall have a length not less than 2½ times the thickness and stretchers not less than twice the thickness.

Stones for backing shall be at least 4 inches thick and have a width not less than the thickness and a length not more than three times the thickness.

Dry rubble and cement rubble masonry stones (rubble stones are of irregular shape and size) shall meet the quality requirements of Type C stone (Table 44, p. 188). They must be free from structural defects, earth, clay, or other foreign substances. Weak points and angles must be removed.

Angle and end stones are to be roughly squared and pitched to line. Exposed face stones must be at least 3 inches thick (vertical), have a width of at least 6 inches and a length (horizontal) not less than 1½ times the thickness but with a minimum length of 12 inches.

Baltimore Gneiss and Chickies Quartzite

There are a number of quarries in the Baltimore Gneiss, which have been worked only a short time owing to the poor quality of the stone. Some was too extensively fractured, others showed excessive weathering of the stone.

The Karpinski Quarry Company, located at Janney, is producing dimension stone from Baltimore Gneiss and Chickies Quartzite. Two quarries north of the Pennsylvania Railroad which have been worked since 1921 by various individuals, were taken over by The Karpinski Company in 1946.

The stone is blasted down, piled by two diesel shovels and sized by hand picking. Production was about 80,000 short tons in 1955 from both Baltimore Gneiss and Chickies Quartzite.

Wissahickon Schist

The DeMarco Brothers quarry south of Janney along U. S. Route 1, and the John J. Duffin quarry about three-quarters of a mile west of Trevose, operated intermittently in the Wissahickon Schist. There was no production in 1955.

Chickies Quartzite

The Morrisey Brothers of Philadelphia operate two quarries at Parkland just north of the Pennsylvania Railroad. The quarries have been worked intermittently since 1941 producing only building stone. Production from one quarry is exclusively for flagstone for a single contractor in New Jersey. The second quarry produces a 6-inch veneer stone and a 12-inch face stone. The stone is tinged a light-green and near the surface is soft and friable. Waste material on the dump is being used for driveway construction.

Triassic sedimentary rocks

Carmillo Buciarelli operates a quarry at Edison. Originally opened in 1930, it was shut down later and reopened in 1948. All rock was for building stone and production was about 1,000 tons per year. Stone produced includes face stone, veneer stone, flagstone, and bridge stone for bridge construction in New Jersey. Production of miscellaneous stone during 1955 amounted to about 19,000 tons.

Delaware Quarry Company operates two quarries. One is along the Delaware River road about two miles north of Point Pleasant, and the other is the Plumstead Township Quarry, southwest of Point Pleasant. Red, purple and black stone are quarried. The red comes from the Delaware River road quarry. Production is 3-4,000 tons per year combined, and includes flagstone, veneer, and bridge stone. The bulk of the stone is trucked to New Jersey for bridge and road construction. The bridge stone minimum dimensions are 8 inches vertical on the face, 30 inches wide, and 24 inches on the back or the depth.

In the early stages of development of the Delaware River road quarry a narrow, vertical, limonite-stained zone was exposed in the center of the face. The zone showed disseminated pyrite, thin coatings on fracture surfaces and vertical pyrite veins as much as one-quarter of an inch thick. The pyrite zone did not continue to the surface but stopped about 20 feet above the quarry floor.

The Lumberville Granite Company at Lumberville is working a large quarry face in arkose of Stockton lithofacies. The rock is medium- to coarse-grained, light-gray to tan and well-jointed.

Triassic diabase

The Triassic diabase, "black granite" or "trap" rock, sells for a higher unit volume price and is the aristocrat of dimension stone produced in Bucks County. There is probably a greater proportion of waste from diabase dimension stone than from other rock types. In past years there were, among the trap rock hills small operations producing Belgian blocks. Trap rock is excellent for Belgian block because of its uniformity and toughness. Much of the production was from boulders. There are a number of abandoned quarries which produced a considerable amount of rough stone, probably for abutments and foundation work. At present, there are only two quarries working in diabase in Bucks County and they produce stone for ornamental purposes and precision instrument bases.

Bradford and Whitaker are operating a small quarry 2½ miles east of Coopersburg. The quarry was opened in 1946 and, in the first few years, production was from large boulders. Practically all of their production is shipped to Brooklyn, New York, where it is used as monument stone for cemetery markers. The monument stone, polished on one face, ranges in size from 3½ feet x 10 inches x 1½ feet to 6 feet x 2 feet x 1 foot. Bradford and Whitaker can polish about 15 square feet per day, and, although they were idle in 1955, they have been producing 4,000 to 5,000 cubic feet per year. About 80 percent of the rock quarried goes to the waste dump.

The rock is quarried and then drilled and split to size with small air hammers and plug drills. Rough surfacing is done with a pneumatic surface cutter. After surfacing, the blocks are placed in the polishing machine. The first polishing wheel uses chilled steel shot (No. 26). The second wheel polishes successively with Nos. 90, 1F, 3F, and 600 carborundum. The final polish is made with a buffing machine.

In addition to the polishing and surfacing equipment, the owners maintain a blacksmith shop, air compressors, water pump, two trucks, motor generators, and necessary quarry equipment. The operating crew consists of three men.

The Coopersburg Granite Company operates a quarry about 3½ miles from Coopersburg on the south side of "The Lookout." The preparation plant is in Coopersburg on the Reading Railroad. At the quarry site large blocks are blasted and split, and then placed on small cars for transport to the gang saw. The largest block that can be handled by the gang saw is 4½ x 9½ x 3 feet. The gang saw consists of notched steel blades one-half inch in thickness which slide back and forth. Steel shot and water are fed into the notches.

The sawed slabs are trucked to the Coopersburg plant for further cutting, trimming and polishing. Considerable trimming is done with small air hammers and by hand. A diamond saw of large diameter is used for final cutting. Chilled steel shot, No. 26, is the abrasive used to start, followed by 70 to 80 mesh carborundum and 180 to 220 mesh carborundum. Final polishing is done with 600 aluminum oxide and with tin oxide. Designs and names are etched by sand blasting. Designs are cut out of a heavy paper which is placed on a polished surface. Garnet sand is blown against the exposed portion of the polished surface.

Production includes cemetery monuments and headstones, polished building stone, store fronts, window ledges, 2 inch-, 3 inch-, and 4 inch-veneer slabs, and surface plates for precision instruments. Monuments designed and constructed by the Coopersburg Granite Company have been erected in many places in the United States (Plate 24, p. 202). The diabase is ideal for surface plates, because of its uniformity and resistance to warping. Slabs can be polished to a guaranteed flatness tolerance of .00005 inches. When two such plates are placed surface to surface, they may be lifted by the top plate without pulling apart. The diabase plates are being used instead of steel plates.

Production is about 5,000 cubic feet per year. Finished rocks amount only to 10 to 15 percent of the rock quarried.

FLUX ROCK, LIME AND CEMENT

Recent production of limestone and dolomite in Bucks County for uses dependent upon their chemical composition is limited now to the making of lime, although no lime was produced in the period 1948 to 1950. Relatively speaking, there was considerable production in the past of flux stone for the Durham iron furnaces. In the late 1800's and early 1900's there were numerous small lime kilns in operation. Cement also was manufactured in Bucks County more than a century ago.

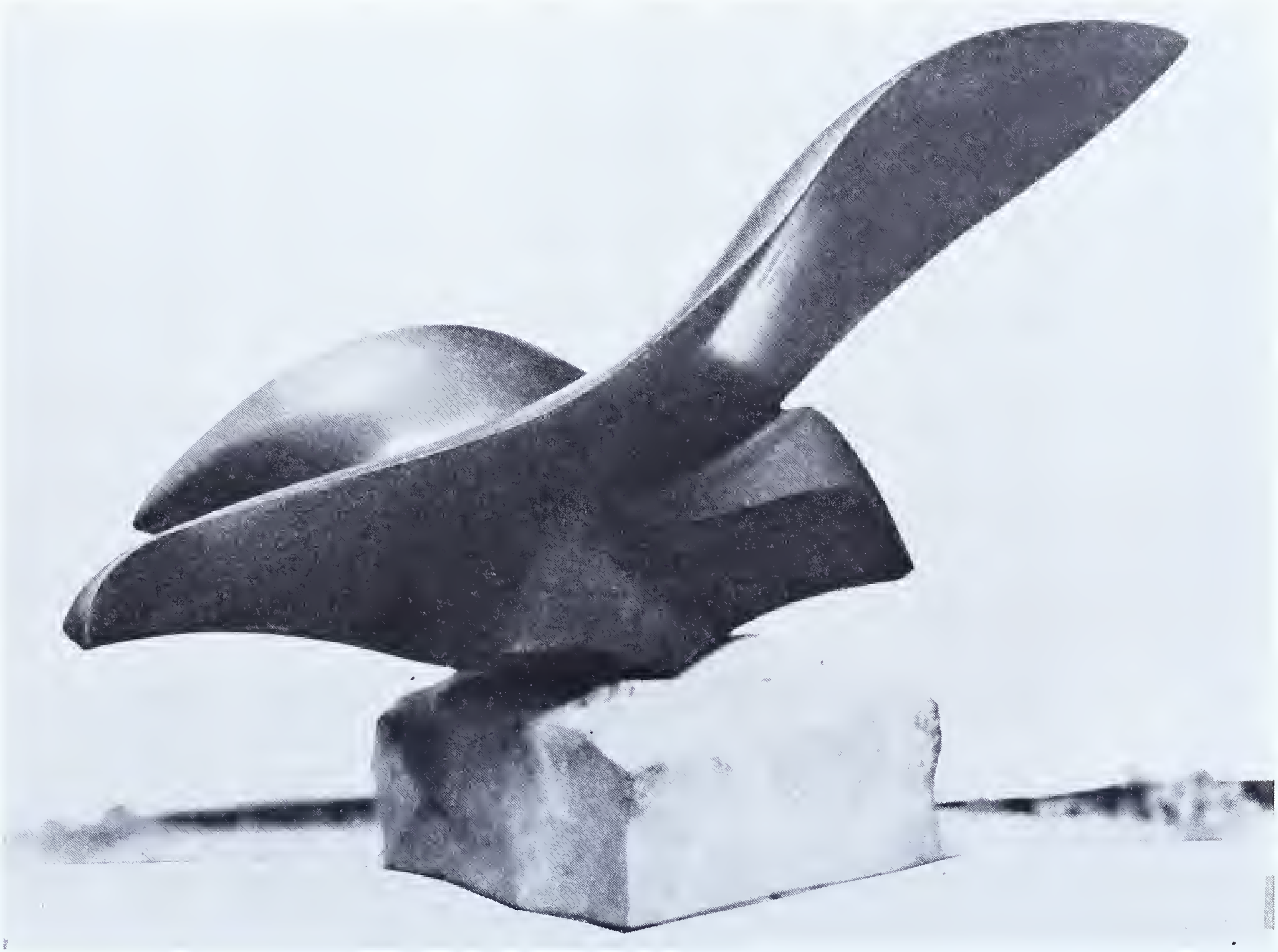
Distribution and Composition

Limestone and dolomite occur in three small areas in Bucks County (Chapters II & III). The Durham area extends from the Delaware River southwesterly to the Northampton-Bucks county line. The belt is half a mile wide and 6½ miles long. The Buckingham area extends from the Delaware River, two miles north of New Hope, southwest to Furlong. This belt is about ten miles long and averages 1½ miles in width.

The third area, which is not important economically, is one mile southeast of Holland near Neshaminy Creek. Here the Franklin Limestone of Pre-Cambrian age is exposed in the Van Artsdalen quarry. Inasmuch as more than thirty minerals have been reported from this locality, it is well known to mineral collectors (Weiss, 1942).

More than one hundred samples were taken to determine the composition of the Paleozoic carbonate rocks of the Durham and Buckingham area. Most of the quarries and larger outcrops in the Durham area were sampled, but only the eastern end of the Buckingham area has been investigated. Analyses of the samples are given in Table 50.

PLATE 24



Sculpture titled "Reconnaissance" by Victor Riu, Coopersburg.

TABLE 50. *Chemical analyses of Paleozoic carbonate rocks of the Durham area*

Locality & Sample No.	*Length of Sample in ft.*	*SiO_2*	*R_2O_3*	*$CaCO_3$*	*$MgCO_3$*	*S*	*Remarks*
1-1	15	.49	2.32	55.31	42.10	.19	Witte farm, 1½ mi. E. of Springtown
2-2	10	1.76	2.34	54.48	42.34	.17	
2-3	7	2.33	3.84	53.11	39.35	.21	Below 2-2
2-4	9	1.30	2.97	54.29	40.92	.24	Below 2-3
2-5	5	32.43	3.07	34.52	27.44	.24	Below 2-4
2-6	5	1.38	2.77	51.93	41.87	.08	300′ E. and 50′ above 2-5
2-7	10	2.40	4.04	53.02	38.13	.21	200′ W. and below 2-5
2-8	7	0.76	2.82	55.48	40.84	.19	50′ W. and 18′ below 2-7
3-9	3½	24.47	9.38	36.29	26.73	.18	Opposite farm house
4-10	8	1.91	3.92	53.71	39.18	.29	Small quarry: stratigraphically above 3-9
4-11	7	7.82	4.44	49.57	36.79	.24	Below 4-10
4-12	9	1.43	4.02	54.29	38.65	.20	In quarry 250′ S of 4-10
4-13	13	6.47	3.87	52.02	36.72	.27	Below 4-12
4-14	10	2.17	4.04	54.88	38.36	.15	Below 4-13
5-15	3	6.19	2.02	52.02	40.06	.29	
6-16	1½	7.28	4.00	50.75	38.61	.21	
7-17	2½	4.45	1.63	53.10	41.26	.24	Small quarry
7-18	9	2.11	2.45	55.48	40.44	.47	Below 7-17
7-19	2½	1.09	3.06	56.06	39.81	.21	Below 7-18
8-20	..	12.72	2.58	48.09	37.81	.21	Small outcrop in field
9-21	..	4.79	2.59	53.10	40.45	.08	
9-22	..	4.30	3.04	53.10	40.31	.20	
10-23	..	3.48	2.31	54.10	40.56	.20	Old quarry
11-24	..	6.87	5.17	51.64	36.30	.23	
12-25	10	2.69	6.08	54.21	35.41	.14	

TABLE 50 (continued)

Locality & Sample No.	*Length of Sample in ft.*	*SiO_2*	*R_2O_3*	*$CaCO_3$*	*$MgCO_3$*	*S*	*Remarks*
13-26	..	2.05	4.72	54.51	38.43	.10	
14-27	7	0.79	4.50	55.31	38.99	.15	
14-28	4	4.97	9.01	54.21	30.20	.14	Below 14-27
15-29	..	0.78	5.15	55.31	36.81	.13	
16-30	8	0.58	4.22	56.16	38.10	.14	
17-31	..	2.04	5.30	52.94	37.60	.09	
18-32	12	10.64	10.12	49.77	27.00	.32	
19-33	..	1.20	4.29	54.67	39.66	.12	
19-34	3	1.04	4.17	55.10	38.68	.13	Below 19-33
19-35	11	4.99	7.44	52.62	33.70	.15	Below 19-34
19-36	15	5.25	7.45	52.62	32.66	.13	Below 19-35
20-37	15	3.27	3.78	54.74	37.50	.22	Small quarry
21-38	20	2.91	2.79	53.26	41.01	.11	Small quarry
22-39	45	3.59	3.73	52.25	39.77	.09	Small quarry
23-40	..	2.63	1.35	53.73	42.26	.08	Small quarry
23-41	..	5.51	4.24	50.00	40.35	.20	Small quarry E. of 40
23-42	..	3.52	3.82	52.42	39.74	.21	Small quarry E. of 41
24-43	20	2.52	3.48	52.67	40.40	.25	
25-44	30	3.23	2.67	54.19	39.73	.07	Quarry
26-45	..	2.80	4.60	52.68	39.31	.10	Furnace quarry
26-46	..	4.47	5.26	52.30	38.15	.09	S of 20-45
27-47	140	7.88	6.43	47.98	37.30	.12	Furnace quarry, east end
27-48	85	3.97	3.88	53.37	37.96	.07	Furnace quarry, west end
28-49	..	12.27	8.23	46.61	31.93	.10	

TABLE 51. *Chemical analyses of Paleozoic carbonate rocks of the Buckingham area*

Locality & Sample No.	*Length of Sample in ft.*	SiO_2	Al_2O_3	Fe_2O_3	$CaCO_3$	$MgCO_3$	*Remarks*
1-1	9	17.05	4.63	1.23	41.90	17.05	
1-2	7½	6.78	0.40	0.98	49.97	41.93	Below 1-1
1-4	19	2.00	0.23	2.45	53.89	42.14	Below 1-2
1-5	12½	2.97	1.15	1.05	52.12	42.30	Below 1-4
1-6	14½	2.35	.23	1.19	55.15	41.35	Below 1-5
2-3	5½	5.48	2.33	1.05	79.39	11.13	
3-7	11	4.99	1.12	1.40	58.90	34.08	
3-8	15	11.70	3.25	1.61	48.05	35.59	Above 3-7
4-9	15	1.41	.17	1.89	62.82	33.91	Quarry
4-10	17	1.08	0.09	0.63	69.18	29.32	
5-11	10	18.40	6.43	1.82	39.15	34.25	Equivalent to beds above 4-9 & 4-10
6-12	5	5.07	2.38	0.73	50.95	40.43	
6-13	20-25	4.13	0.82	0.52	51.79	42.32	2′ above 6-12
7-14	25	18.78	9.21	1.54	38.80	32.50	
8-15	15	10.16	4.56	1.44	49.05	34.43	
8-16	12	8.33	5.91	0.91	62.65	21.66	Above 8-15
8-17	3½	3.39	1.26	0.28	81.89	13.45	Below 8-15
8-18	13	10.19	7.22	1.02	53.01	28.78	Below 8-17
9-19	5	10.74	2.67	1.26	45.93	39.27	
9-20	2	23.02	2.81	1.19	53.59	19.12	
9-21	4	15.61	8.02	1.46	41.21	34.46	
9-22	20	70.19	4.47	1.07	12.95	11.31	
9-23	11½	20.31	5.77	1.40	38.98	32.55	
9-24	5	27.53	7.93	1.96	32.72	29.48	
9-25	12½	7.43	1.03	0.98	49.47	41.09	
9-28	12	12.46	4.18	1.15	44.04	37.82	
9-29	15	12.40	2.97	0.87	45.78	37.82	
9-30	16½	11.97	3.69	1.12	44.98	38.19	
9-31	14	6.97	1.11	0.77	50.09	40.95	
9-32	18	3.72	2.79	0.70	51.40	41.31	
9-33	15	7.08	3.58	0.98	47.88	40.56	

TABLE 51 (continued)

Locality & Sample No.	*Length of Sample in ft.*	SiO_2	Al_2O_3	Fe_2O_3	$CaCO_3$	$MgCO_3$	*Remarks*
9-34	15	5.59	2.24	0.80	49.80	40.91	
9-35	8½	3.27	2.13	0.80	51.70	42.00	
10-36	9	7.35	3.58	0.28	71.92	14.93	
10-37	1½	5.47	1.23	1.35	60.05	31.88	
10-38	6	6.58	2.62	0.56	82.49	6.65	
10-39	8½	3.24	1.40	0.63	73.80	20.54	
10-40	8	4.25	1.96	0.56	73.99	18.39	
10-41	10	5.44	1.66	1.04	71.42	18.88	
11-42	6½	6.63	2.19	1.12	48.96	41.27	Stratigraphically above 9-19
11-43	6	17.90	7.00	1.53	38.04	34.69	Above 11-42 but gap between
11-44	7	10.90	3.69	1.01	45.03	38.89	Above 9-19 & 11-42; relation to 11-43 unknown
12-45	12	13.73	6.24	1.56	62.00	15.88	Quarry
13-46	10	2.35	1.32	0.84	52.52	43.63	Below 13-46
13-48	10	5.53	2.65	0.98	49.80	41.67	Below 13-47
13-49	6	2.24	0.91	0.70	52.62	44.18	Above 13-46
13-50	10	7.83	3.15	0.77	48.09	40.87	Above 13-49
14-51	7	4.61	1.44	0.73	50.74	42.56	Quarry across creek from 13-46
14-52	6	1.97	0.68	1.01	52.56	44.00	Below 14-51
14-53	5½	1.63	0.76	0.70	51.37	44.81	Below 14-52
14-54	9	6.05	1.37	1.08	49.49	41.44	Below 14-53
14-55	5½	2.18	1.09	0.80	52.47	44.37	Below 14-54
14-56	11	3.81	0.93	0.91	51.26	43.14	Below 14-55
14-57	4	1.89	0.77	0.91	53.51	43.62	Below 14-56
15-58	4	6.41	1.55	1.01	48.45	42.24	
15-59	9	3.01	0.92	1.02	49.07	44.86	10′ below 15-58
16-60	5	8.26	1.14	0.84	48.27	41.27	
17-61	4	7.85	1.67	0.77	48.50	40.78	
17-62	2½	19.50	5.72	1.33	38.17	35.16	Below 17-61
17-63	2	13.64	1.24	0.98	45.37	37.85	Below 17-62

The analyses of Bucks County carbonate rocks reported by Miller (1934, p. 246-255) are presented in Chapter III in the discussion of the Paleozoic rocks. Inspection of the tabulated analyses indicates that the carbonate rocks in the Durham area and the bulk of the Cambrian carbonate rocks in the east end of the Buckingham area are dolomites or impure dolomites. The ratio of $CaCO_3$ to $MgCO_3$ holds closely to that of theoretical dolomite even though the percentage of $CaCO_3$ and $MgCO_3$ vary with increasing silica and alumina. The distribution of samples is sufficiently random that one may assume they are representative of all the carbonate rocks in the two areas.

It is difficult to visualize the relationships of the several oxides and carbonates or certain ratios of oxides to one another in tabulated form. Graphical presentation, however, shows these relationships in a single plot and makes possible the determination of any constant relationships or trends.

Several types of diagrams and some of their uses have been described and discussed by Gault (1951). Three types of diagrams are used for plotting carbonate analyses. Most analyses of carbonate rocks report four or five constituents, namely SiO_2, R_2O_3 or Al_2O_3, and Fe_2O_3, $CaCO_3$ and $MgCO_3$. These five oxides will ordinarily account for 98 percent or more of the rock. The three diagrams combine these five oxides in the following ways: (1) $SiO_2 + R_2O_3$ (or $Fe_2O_3 + Al_2O_3$) – $CaCO_3$ – $MgCO_3$; (2) total CO_3 – SiO_2 – R_2O_3 (or $Al_2O_3 + Fe_2O_3$); and (3) SiO_2 – Fe_2O_3 – Al_2O_3 (recalculated to 100 percent). The first type of diagram is called the dolomite diagram, and from it is determined how close the carbonate fraction is to that of theoretical dolomite. The second or carbonate diagram indicates the relationship between the carbonate or chemical fraction and the clastic fraction, and also shows the SiO_2/R_2O_3 ratio. The third diagram describes the chemical ratios of the clastic fraction.

Figures 5 and 6 of Gault's investigation of carbonate rocks (1951) are plates of the analyses in Tables 50 and 51. High calcite rock and/ or low silica rock for fluxing stone is practically absent, as the average SiO_2 plus R_2O_3 content is about 5 percent. The overwhelming predominance of high $MgCO_3$ stone rules out the possibility of obtaining materials for cement manufacture.

Production

Production statistics are not available. An approximation of the total volume of stone quarried might be obtained by calculating the volumes of the abandoned quarries. Relatively, however, the total tonnage would be very small in comparison with such other areas as the cement belt of Lehigh and Northampton Counties or the dolomite quarries of Chester and Montgomery Counties.

Flux stone was an important product when the Durham iron furnaces were in operation. Production was relatively small in comparison with the demands of steel companies today. The silica content of the Durham flux stone would be too high to meet present-day requirements.

The production of lime might be equal to or greater than the total production of fluxing stone but most of it was from small, local kilns which supplied the market in their immediate vicinity. It has been reported that the quarry south of Aquetong owned by Mrs. J. Nichols produced 18,000 to 30,000 bushels of lime per year when in operation. This is one of the largest quarries in Bucks County.

The manufacture of cement in Bucks County dates back to 1829. Although two plants are known to have operated, only one used rock from Bucks County. An account of the old operations by Dr. B. F. Fackenthal is given in Miller (1934, p. 253).

MINERAL PIGMENTS

Umber and ocher have been mined for mineral pigments at a few places in Bucks County. A small operation was reported in the Buckingham Mountain area, but the only working site in the past few years is on the Witte farm, about one mile northeast of Springtown.

Both ocher and iron ore have been produced in small quantities from this area. The material is typical of the brown ores of the Appalachian region and consists essentially of hydrated iron oxides and clay. Small and large nodules, and angular masses of limonitic material as well as ferruginous clay were recovered. The latter is used as mineral pigment by a paint manufacturer in Bethlehem, Pennsylvania.

Iron ore was produced from Bucks County during the Revolutionary War days, and again during the Civil War. Mining has always been spasmodic. Some ore was mined for the Durham furnace in the 1880's. During World Wars I and II umber was mined.

The ferruginous materials are residual products of weathering of sedimentary rocks. Lack of outcrops prevents working out the detailed geology. Apparently there are, or were, several deposits of the ferruginous material at the contact of Tomstown Dolomite (Leithsville Limestone) with Hardystone Quartzite or within Tomstown Dolomite (Leithsville Limestone) near the contact. The sedimentary rocks dip about 40° S. The paint rock ranges from three feet to forty feet in thickness and is pockety. The zone apparently extended for at least one-quarter of a mile along the strike, almost entirely in Tomstown Dolomite (Leithsville Limestone).

Although there are some indications that shafts had been sunk, operations are now by open pit. The present operating pit lies immediately east of an abandoned pit. The ocher is taken by truck to the plants of paint producers.

Only scattered production figures are available. It has been reported that 60,000 tons of ore were taken from the area during the Revolutionary War. Production of iron ore since then has probably been much less. In recent years production of ocher has been about 500-1,000 tons per year. Tonnage figures for ocher production in the period 1941-1947 have been reported by the owner as follows:

1941—1,336 tons
1942—1,181
1943—1,326
1944— 976
1945— 570
1946— 519
1947— 567

A royalty of $1.00 per ton is paid on the ocher by the producer.

CLAY AND CLAY PRODUCTS

The principal production of clay in Bucks County has been and is for brick making, though some pottery is also made. Production of clay and shale in Bucks County has been confined to the Triassic shales of Brunswick and Stockton Lithofacies.

Operating Plants

Hyzer and Lewellen operate a furnace lining and burner base plant at Southampton, Pennsylvania. None of the raw materials is from Pennsylvania. Products include cast and molded, dried or baked mixtures of South African vermiculite, Portland cement, and New Jersey clay.

The Moravian Pottery and Tile Works, Doylestown, uses shales of Stockton Lithofacies from local pits. This unusual and interesting operation produces ornamental and floor tile for use in cathedrals, fireplace fronts and so on. Some of the decorative tiles in the Capitol at Harrisburg were made here. All molding and firing is done by hand.

The Quakertown Brick and Tile Company, Inc., one mile north of Quakertown, the only company which reported production in 1955, commenced operation in 1947. Triassic red shale of Brunswick Lithofacies, the principal raw material, is obtained from a quarry near the plant. The rock is dug with a power shovel, loaded into trucks and dumped into a grinding bin. The ground rock is mixed with water, molded, cut, loaded on kiln carts, dried, and fired. The product is a red building brick which shows slight shrinkage. An iron silicate bond imparts strength to the brick. More than 20,000 short tons of clay were quarried by the Quakertown Brick and Tile Company during 1955.

SLAG PRODUCTS

Although slag is the product of iron manufacture and therefore is not, strictly speaking, a mineral resource, it is a product of treatment of mineral resources. The old slag dumps of the Durham furnace were quarried for use in the manufacture of rock wool and for driveway construction. It is reported to be excellent for rock wool manufacture. Production was 300-400 tons per day. Around 1920 some was used for ballast for trolley tracks. The American Slag Company, Easton, Pennsylvania, quarried slag along the Delaware River from 1947 to 1950. In 1951 production was principally from stockpiles. The slag was removed with power shovel and dragline and then crushed. Four sizes were produced.

For driveway and parking lot construction:
1. 2A modified
2. between 2A-3B

Rock wool manufacture:
3. 1½ to 3 inches
4. 3 to 5 inches

In Table 52 is a chemical analysis furnished by the American Slag Company.

TABLE 52. *Chemical Analysis of slag from dumps of Durham Furnace, Pennsylvania*

SiO_2	39.55
Al_2O_3	9.44
Fe_2O_3	0.94
Mn_2O_3	2.48
CaO	26.87
MgO	17.38
CaS	.70
	97.36

SILICA REFRACTORIES

A small tonnage of Chickies Quartzite has been produced from the quarries of R. M. Platt at Somerton Springs, Pennsylvania, for furnace and cupola linings in the steel industry. Steel companies in Pennsylvania and New England have taken the bulk of the production. The product is sold under the trade name "Pyrosil." Production has averaged about 1,000 tons per year but recently has fallen off.

Building stone is also taken from the quarries and has been shipped as far as Cleveland, Ohio. Chemical analyses of the rock are reported in Table 53 as follows:

TABLE 53. *Chemical analyses of Chickies Quartzite from Somerton Springs, Pennsylvania*

	Hard	*Soft*
SiO_2	92.5%	91.5%
Al_2O_3	6.9	7.0
Fe_2O_3	0.4	0.4
MgO	0.1	0.1
CaO	None	None
Loss	1.0	0.9
	100.9	99.9

BARITE

by

H. R. GAULT AND E. W. TOOKER

Barite, also known as barytes or heavy spar, is barium sulphate. Pure barite contains 65.7 percent BaO and 34.3 percent SO_3. Its specific gravity (4.3-4.6) is high for a light-colored, nonmetallic mineral and thus is characteristic. Barite is used chemically as a source of barium, and pulverized for suspension in muds in oil well drilling, and as a filler in paper, rubber, paint, and oilcloth.

Barite has been reported at three localities in Bucks Countly. Production was from one occurrence near Buckmanville (Eyerman, 1911).

Buckmanville Locality

The Buckmanville locality is the largest deposit of barite of the three in Bucks County. It has been mentioned in several reports by Bascom, Darton, and others (1909b); Eyerman (1911); and Stose (1939). The most recent and complete study is that by Tooker (1949). Most of the following description is taken from his account.

The Buckmanville deposit is three-fourths of a mile southwest of Buckmanville, Upper Makefield Township on Pennsylvania Route 232. The barite lies on the property of Mrs. Thornton Lewis, Newtown, Pennsylvania. Interest in the occurrence from an economic standpoint has been slight because of its small size and the paucity of outcrops. No production records are available.

The country rock, indicated by float, is red sandstone of Brunswick Lithofacies. Diabase and hornfels float have also been noted. The sandstone apparently dips 12° to 40° NE. The barite occurs in brecciated sandstone. Six pits range in size as follows: 10 to 40 feet long, 5 to 30 feet wide, and 5 to 25 feet deep. With eight smaller pits, these constitute the workings which lie in a small woods at the summit of a hill. The area of old workings is about 450 by 150 feet, but barite float is present over an area of about 30 acres. Abundant barite float occurs in an adjacent cut on Route 232. The pits and dumps are overgrown, and there are only a few exposures of bedrock.

In addition to barite, Tooker (1949) identified quartz, chalcedony, sericite, orthoclase, plagioclase, hematite, magnetite, pyrite, chalcopyrite, malachite, and limonite in the barite-bearing breccia. The barite is transparent white to yellowish. It occurs as 1) aggregates of parallel plates half an inch to two inches long and one inch wide, 2) clusters of radiating plates, 3) single tabular crystals, and 4) disseminated anhedral grains. The barite is found in the breccia as 1) fitted spaces between breccia fragments; 2) cavities in the breccia fragments; 3) irregular veinlets, and 4) disseminated grains. The modes of occurrence grade into one another.

The general paragenetic sequence seems to have been:

Brecciation
Quartz veins (two or three stages)
Sulfides
Barite
Malachite and limonite (weathering)

Tooker (1949) attributed the origin to deposition from ascending hydrothermal solutions which were related to a deep-seated diabase source. The near-by Buckmanville fault probably served as a channelway, and the breccia afforded space for concentration and deposition.

Heavy mineral separation of several specimens of float from the area of the workings indicates that the breccia contains 50 to 75 percent barite by weight. The deposit, which would require beneficiation to make a marketable product, seems to be too small to be of economic importance. Further prospecting does not seem warranted.

Ingham Spring Locality

Barite float occurs near Ingham Spring, Solebury Township, two miles west of New Hope on a side road south off U. S. Highway 202. Several small abandoned pits and dumps indicate some prospecting and possibly quarrying in this area. The deposit is in or near the Furlong fault which brings Cambrian Conococheague (Limeport) Limestone in contact with Triassic sandstone and shale of Brunswick Lithofacies.

Barite float can be traced intermittently for about 700 feet south west from the principal pit. The float material beyond the pit apparently is restricted to slight rises barren of vegetation. The pit and two barite areas lie on a line trending N. 60° E. Black chert float also occurs and can be traced beyond the limits of the barite.

The barite is similar to that of the Buckmanville locality. It is in a brecciated and silicified red sandstone as cavity fillings, vein fillings and disseminated grains. Quartz, the chief associated mineral, lines vugs and veins. Traces of chalcedony, pyrite, chalcopyrite and hematite are also associated.

Stone (1935, p. 8) reports that a sample collected by B. F. Fackenthal, Jr., was analyzed as follows (Table 54):

TABLE 54. *Chemical analysis of a barite sample from Ingham Spring locality, Solebury Township*

SiO_2	17.23	Al_2O_3	0.57	MgO	0.15
BaO	52.07	Fe_2O_3	0.45	P_2O_5	0.09
SO_3	27.17	CaO	0.36	Mn	0.00

Durham Locality

Bayley (1941) described a third occurrence of barite in Bucks County in the Durham mine, Durham, Pennsylvania. A test pit on the south slope of Mine Hill exposed ore described as follows (Bayley, 1941, p. 73):

> . . . an aggregate of little grains and crystals of hematite in a white material which in some specimens is granulated milky quartz and in others is a mixture of milky quartz and a very fine-grained mass of soft white barite . . . In some specimens the material is exclusively barite, the quartz being restricted to a few small glassy grains scattered through the finely granular white barite mass.

An analysis of specimens of the ore showed:

SiO_2	4.77%
Fe_2O_3	81.74
$BaSO_4$	13.80

The ore is in Pre-Cambrian gneiss, but Bayley (1941) thought that the barite is much younger and was derived from the Triassic sediments and introduced into pore spaces in the crushed rocks.

IRON ORE

In colonial days Bucks County was an important producer of iron ore and iron products. The Durham mines are among the oldest in the United States, and the iron furnace at Durham Furnace was probably the second one erected in Pennsylvania. The best descriptions of the history and geology of this mine are by Billinger (1939) and Bayley (1941). The location of long since obliterated workings were reported by McCaskey (1907). Due to the long inactivity in the Durham area and recent road and home construction, essentially all evidence of the old workings has been destroyed or covered. Outcrops are practically non-existent, and only one former mine opening is accessible. On the basis of published information and what can be observed in the area now, it does not appear likely that the Durham mines will ever contribute again to iron ore production. There undoubtedly is some ore still remaining but the very small tonnage of concentrating grade ore offers little hope that any mine can be reopened.

History of the Durham Mines

The existence of ore was known as early as 1698, and the first mine may have been opened about that time. The Durham Iron Company, however, was organized in 1726 by a group of men prominent in colonial affairs, and a furnace was built and began operating in 1727. It continued to operate intermittently until 1789. Cannon shot was made for the French and Indian War and much shot and shell were made for the Continental Army during the Revolutionary War.

From 1789 until 1848 the Durham mine and furnace were idle, and in 1874 the last Durham furnace was built. Ownership of the furnace changed hands in 1901 and it finally shut down in 1908.

Geology of the Durham Mines

The ore lies in a ridge of Pre-Cambrian rocks. Two groups of ore bodies have been worked, one on Rattlesnake Hill and one on Mine Hill. The Mine Hill deposits were first operated from open pits, short tunnels and shallow shafts. In 1859, a 2,000-foot tunnel was driven south into the ridge and was known as the "new tunnel." About the same time an opening was made on the south side of the ridge and later a 200-foot slope was sunk. Three ore shoots were encountered in the slope and furnished the bulk of the ore in the 1800's.

Operations on Rattlesnake Hill began with an open cut in 1851. Later a tunnel was driven from the north slope of the ridge and intersected two ore shoots, the Rattlesnake vein and the Back or South vein. A slope was opened on the vein and ore stoped from levels out from the slope.

The Hollow tunnel was driven from the east slope of the ridge just above the level of Durham (Cook) Creek and into a pocket of ore. About twenty years later a second Hollow tunnel was driven from a point 75 feet south of the first one. The Back vein was intersected 500 feet from the portal and the tunnel then followed the vein. A crosscut intersected the Rattlesnake vein 175 feet beyond. Ore was mined until 1906.

The Mine Hill ore bodies are reported to have had maximum dimensions as follows: 30 feet wide, 500 feet long and 40 feet high; 12 feet wide and 300 feet long; and 18 feet wide and 300 feet long. Rattlesnake vein, ranging from two feet to 50 feet in thickness, averaged 12 feet in thickness. The Back vein ranged from six inches to 10 feet in thickness. Small amounts of ore were also taken from several openings south of the Durham mines tract.

Hematite was the principal ore mineral in the Mine Hill deposits, but there was also some magnetite. Some ore was blue and some was red. Quartz was the principal gangue mineral. The ore was a mixture of hematite (and magnetite) and quartz. The quartz was granulated and the ore minerals were scattered more or less uniformly through the quartz. Bayley states (1941, p. 74) that the ore from Rattlesnake Hill is more nearly like that in the magnetite veins of New Jersey than that of Mine Hill but differs in containing more hematite. Some of the ore from test pits southwest of the open pits on Mine Hill showed barite. Bayley (1941) considered the barite to have been introduced into crushed ore at a later date and that the barite may have come from the Triassic beds of the Newark Group which are in fault contact with the gneisses about one mile south. The occurrence of barite at Buckmanville and Ingham Spring of Triassic age suggests that the Durham barite is related to Triassic mineralization (p. 210).

Bayley (1941, p. 61) writes about the origin of the ores as follows:

> . . . it is concluded that the ores associated with the gneisses and schists are of magmatic origin—that is, the source of their material is thought to be the deep-seated molten magmas, which upon being intruded into the overlying rocks solidified as the various gneisses now constituting the principal rocks of the Highland ridges. After the partial cooling of the gneisses they were in turn intruded by ferruginous portions of the same magma that gave them birth, producing pegmatites and hornblende-augite masses, and these intrusions were later enriched by iron-bearing solutions or vapors originating in the same subterranean source. In their transit to the surface these solutions or vapors deposited additional magnetite in the intruded ferruginous rocks, perhaps replacing some of the earlier minerals, and made the ore lenses that now constitute the ore bodies. The tiny veinlets of magnetite that are so common in the ore veins indicate that the ore-bearing solutions were of low viscosity.

Analyses of the ore as reported by Bayley (1941, p. 72 and 75) are given in Table 55:

TABLE 55. *Analyses of iron ore from Durham Mines*

	1	*2*	*3*
SiO_2	30.45	29.27	25.84
Al_2O_3	.96	.41	2.22
Fe_2O_3	61.07	67.57	56.73
FeO	5.66	1.53	11.50
MgO	.17	.21	.82
CaO	.07	.59	.16
Na_2O	.00	tr.	.28
K_2O	.00	tr.	.73
TiO_2	.103	. . .	.30
MnO_2	.10	–MnO	.10
P_2O_5	.060	tr.	.096
S	.127	0.24	.105
H_2O+	1.15	. . .	1.00

1) Mine Hill, sample from dump of 4,000 tons at mine representing an average of the ore produced in 1885, P. W. Shimer, analyst.

2) Mine Hill, red ore from underground workings, F. W. Maynard, analyst.

3) Rattlesnake Hill sample from dump of 2,000 tons, August 1885, P. W. Shimer, analyst.

Other Iron Ores

Titaniferous magnetite ore has been reported on the Kohl property about one mile southeast of Durham and on the Nicholas property two miles southwest of Durham. The Kohl ore contained 5.95 percent TiO_2 and the Nicholas ore 2.86 TiO_2. The Durham mine ore was essentially non-titaniferous (Table 55, p. 214).

Limonite iron ore was produced in small quantity from the Orchard mine 800 feet south of the Hollow tunnel in Rattlesnake Hill. Ore was mined from 1849 to 1876. A partial analysis gave Fe, 46.71 percent; P, 0.39 percent; and insoluble, 7.36 percent.

Bascom and others (1931) report that a small amount of magnetite was mined from a pegmatite half a mile south of Dillingerville but the mine was abandoned in 1913.

GRAPHITE

Graphite, one of the native forms of carbon, is also known as black lead and plumbago. The principal uses of graphite are for making crucibles and other refractory products used in the steel, brass, bronze and electro-chemical industries and for lubricants. It is also used in "lead" pencils, metallic paints, foundry facings, electrodes and stove polish.

Miller (1912) discussed graphite in Pennsylvania and mentioned some production from Bucks County where it apparently was first mined in the State. The mines were located near Trevose and Langhorne in Pre-Cambrian gneiss.

LEAD AND ZINC

A small tonnage of lead and zinc is reported to have been produced from veins in Triassic shales near New Galena, Pennsylvania. Although a satisfactory history of the activities in this area is not available, the best discussion of the early history is given by Miller (1924). The most recent account of the deposit is by Earl (1950).

History

It has been said that lead was obtained from this area during the Revolutionary War but Miller (1924) could not verify this and was not inclined to accept it. Although galena is reported to have been identified here in 1856, the most likely discovery date seems to be 1860. A Mr. Dickinson of Philadelphia took an option on the property after a large block of ore was uncovered in a post-hole and smelted in a blacksmith shop. In 1861 Jacob and George Neimeyer bought the property and began active exploration work. Miller (1924) stated that they sold the property to a New York company.

Between 1861 and 1921 reports on the prospect are vague and conflicting. Further exploration and efforts to operate apparently were undertaken at several instances but the results were negligible. Lyman (1895, p. 2,631) states:

> Doan's mine, at New Galena, on the North Branch of the Neshaminy, in New Britain Township, three miles and a half northwest of Doylestown, was opened about 1863, was worked a little as late as 1888, and according to a newspaper account was about to be reopened in 1891, to be worked six months under an option to purchase in case the vein of ore should be found to be twelve inches wide. When visited in 1889, the mine was a hole some fifty yards long by twenty yards wide, full of water and quite inaccessible. It is said to be fifty feet deep. The dump showed very little galena indeed, much quartz, specks of copper pyrites, traces of malachite and a little zinc blende. The country rock appears to be blackish gray hard shales. It is not at all probable that any workable vein exists here. The mine is geologically about 800 feet above the bottom of the Gwynedd Shales.

The Guerdon Glen Lead Company acquired the property in 1921. Up until the time of Miller's report (1924) the company carried on no active mining but merely worked over the dumps and did some surface development. The record of activity subsequent to Miller's report is vague. Local inhabitants report that someone examined the property in the early 1930's and may have dewatered the underground workings.

Other than this activity apparently such mining as has been done took place prior to 1920 and probably by the Neimeyers (1860's). Annear's report (Miller, 1924) indicates an extent of workings which compares favorably with what can be guessed at today from surface dumps and shaft sites.

In 1948 the U. S. Bureau of Mines examined part of the area and put down two diamond drill holes (Earl, 1950). According to their map, activities were restricted to the workings on the south side of the Creek.

Workings

The best description of the workings is quoted by Miller (1924) from a report prepared by John Annear for the Neimeyers. The only other accounts known are by Lyman (1895), and Earl (1950), and they say very little. All that remains today are old dumps and slumped and water filled pits and shafts. Northeast of the crossroad and south of North Branch Neshaminy Creek are a large, water-filled pit and a few small depressions indicating old pits to the northeast. Southwest of the road on the south side of North Branch Neshaminy Creek are a number of small pits on the approximate extension along the strike of the large water-filled hole. These pits and dumps on the south side of North Branch Neshaminy Creek are shown in maps in reports by Miller (1924) and Earl (1950). On the north side of North Branch Neshaminy Creek, several hundred feet northeast of the large water-filled hole, are the remains of three shafts. There is more dump material around these shafts than anywhere else in the area. The amount of material in these dumps indicates at least 150 feet of underground workings. Oddly enough, these shafts are not shown on Miller's or Earl's maps, although they are very accessible. They lie near the northeast extension of a line connecting the pits southwest of the road and the large water-filled hole.

Geology and Mineral Deposits

The country rock in the vicinity of the mine at New Galena consists essentially of Triassic dark-gray shales, silty shales, and siltstones of Locktong Lithofacies. A diabase sill crops out about 1,000 feet southeast of the main pit, and Miller (1924) states that diabase was found on the dump. The Bureau of Mines drill holes did not cut the diabase. The shales trend northeast-southwest and dip about 20° to 30° NW.

The veins represent fillings and replacements in sheared and brecciated zones dipping southeast which may be related to a fault zone inferred by McLaughlin (Plate 2, in pocket). The angle and dip is not known but a mineralized zone in one drill core projected to the surface workings suggests an angle of 70° SE to vertical. Earl (1950) states that the ore dips 70° SE. The veins trend northeast for unknown distances, but from the Annear report and the distances between dumps and shaft sites, one can infer an extent of at least 800 feet. The number of veins is unknown. Annear's description suggests two with a split from one vein. He mentions the "Dickinson vein" which appears to run parallel "to the Lode" at a distance of about thirty-five feet.

As reported by Annear (Miller, 1924), thicknesses of the veins range from 18 inches to three feet. The mineralized zone in the Bureau of Mines drill hole #1 as logged by the writer, is about four inches thick and at a depth, in the hole, of about 145½ feet. Annear gives a width of four inches to the split or "Dropper" from the Lode.

The ore, as described by Miller (1924) and from specimens collected on the dump, is a coarse-grained aggregate of galena, sphalerite, and fragments of country rocks. Associated minerals are pyrite, chalcopyrite, calcite, dolomite, ankerite, and bornite (Miller, 1924). Some specimens show a rude banding, others are structureless. In some specimens sulfides make up the bulk of the vein; in others there are only minor amounts of galena disseminated through brecciated rock. The contact with the wall rock is sharp in some places and the wall rock is not fractured. In other specimens the contact is well defined but the wall rock is intensely brecciated. Small stringers two to 10 mm thick of calcite, quartz, and sulfides enclosing fragments of wall rock have been observed.

Quartz is the most abundant material filling the open spaces in the breccia where sulfide minerals are scarce. Vugs and druses are common. Galena appears to have been the most abundant sulfide, but in many specimens sphalerite is the only sulfide mineral. The sphalerite is light brown to almost yellow.

The New Galena lead prospect is an interesting occurrence of base metal mineralization in Triassic rocks. It is doubtful, however, that it should be regarded as anything other than a mineral occurrence. Data are scanty but the evidence indicates only a small deposit.

The horizontal extent of the mineralization indicated by the workings, would lead one to expect a greater vertical range for the veins than is indicated by the Bureau of Mines drill holes. The holes show, however, that the ore has pinched out downward or disappeared in less than 100 feet from the surface. Assuming that the drill holes were carried far enough into the footwall side of the mineralized zone, it is suggested that the ore occurs as small lenses or shoots scattered along a zone of faulting and brecciation. It is unfortunate that the area northeast of the shafts on the north side of North Branch Neshaminy Creek was not tested by drilling, if for no other reason than to verify the apparent disappearance of the veins in depth suggested by holes 1 and 2.

COPPER

There are many places in Bucks County where copper minerals have been reported in minute amounts. Wherry (1908) listed seventeen occurrences of copper in Bucks County. Most of these occurrences are related to the diabase intrusions, either in metamorphosed sediments or in fissures presumed to intersect diabase sheets. Wherry stated (1908, p. 727) that the Dutch did some mining at Bowmans Hill at least as early as 1650. The primary minerals are chalcopyrite and bornite. In many specimens the primary minerals have weathered to green malachite and chrysocolla or blue azurite. The brightly colored weathering products attracted attention in the past. Prospect pits were sunk at places where copper minerals were indicated but none are known to have been worked for copper. There is nothing to justify any expectation of developing a workable copper deposit in Bucks County.

GOLD

Gold has been reported from time to time in gravels and bedrock in Bucks County, but no valid data indicate anything other than the merest trace. Many years ago a shaft, reported to be 90 feet deep, was sunk for gold near Naceville. The rock in the dump is altered shale carrying considerable epidote, indicating extensive alteration, but no related mineralization was noted.

Wherry (1908, p. 732) states:

> . . . In the Haycock sheet near Rockhill Station, in Bucks County (loc. 10), there is a small area of unusually coarse-grained diabase (gabbro) in which a find of 3½ ounces of gold to the ton was reported in the local newspapers. It developed later that this was a fraud, but, strange to say, the rock actually did prove to contain gold, assays made under the writer's direction, upon material collected by himself, yielding about $1.00 to the ton. Reports of gold, silver and platinum elsewhere have, however, in every case turned out to be false.

CHAPTER VII

GEOLOGIC HISTORY

by

BRADFORD WILLARD

The preceding chapters describe and discuss the rocks of Bucks County. A summary of the geologic history and the contributions to geology made in this publication follow.

PRE-CAMBRIAN

The oldest rocks in Bucks County give little information of the earliest geologic events. Except for the fact that these rocks are Pre-Cambrian, their age has not been made known. Radioactive age determinations are not available, nor have any other means been found for indicating ages with certainty. If the Byram and Pochuck Gneisses are younger than the Franklin Limestone in Northampton County (Fraser 1939, p. 159-203), and, if Franklin Limestone is the correlative of the Grenville Limestone, then the Byram and Pochuck Gneisses should be middle to late Proterozoic. Their lithology, interrelationships, and degree of metamorphism indicate a long interval of deposition, igneous intrusion, and metamorphism. During the epi-Proterozoic interval, profound erosion cut the ancient rocks down to a reduced surface upon which the oldest Paleozoic sediments were laid.

The Pochuck Gneiss, generally admitted to be of igneous origin, and the Franklin Limestone are the oldest rocks. The presence of considerable carbon in the Franklin Limestone as graphite flakes, and the graphite formerly exploited from rocks of the same age elsewhere in Pennsylvania, are significant as evidence of the presence of life. Into these ancient rocks was injected the granite that today is seen altered to the Byram Gneiss. The invading igneous rocks assimilated much of the wall and roof rock, but small to large patches of Pochuck Gneiss and one small exposure of the Franklin Limestone remain in Bucks County. The Byram Gneiss may be the upper part of a batholith which engulfed all but the remnants of Franklin Limestone and Pochuck Gneiss.

The Pre-Cambrian igneous activity may have some bearing on the genesis of the iron ores of Mine and Rattlesnake Hills. According to Bayley (1941, p. 6-61), "The ore veins in the gneisses are not essentially different from layers of Pochuck gabbro-gneiss. . . . it is concluded that the ore associated with the gneisses and schists are of magmatic origin . . ."

Sometime following the granitic intrusion, an interval of orogeny metamorphosed the granite to Byram Gneiss, and further altered the Pochuck Gneiss and Franklin Limestone. That this alteration occurred during Pre-Cambrian time is indicated by the less altered pegmatites which cut the gneisses but are not younger than the Cambrian.

The question of time of metamorphism is tied in with the age of pegmatite formation. Pegmatite dikes are reported cutting Franklin Limestone, Byram and Pochuck Gneisses, and basal Cambrian Hardyston Quartzite. None are known to penetrate younger rocks in eastern Pennsylvania. The pegmatite in Hardyston Quartzite can be no older than early Cambrian. Was there more than one interval of pegmatite formation? A few bits of evidence point to an early Cambrian age of all the pegmatites. There is no indication that any of the pegmatites terminate in the Pre-Cambrian and are assignable to that age. Petrographic variations among the pegmatites are attributable to dissimilarities among the intruded rock—rather than variations in the original composition of the pegmatites themselves. Examination of the pegmatites in the Pre-Cambrian gneisses and comparison with those in Hardyston Quartzite fail to indicate any appreciable difference in degree of metamorphism.

PALEOZOIC

With the opening of the Paleozoic era, the Appalachian geosyncline was formed. From then, until nearly the close of the Paleozoic era, a long, narrow seaway stretched from the Maritime Provinces of Canada to Alabama and included a large part of Pennsylvania. To the east rose the old landmass, Appalachia; to the west spread, intermittently, a shallow, interior sea.

At the start of the Paleozoic era, the sea in the Appalachian geosyncline spread into eastern Pennsylvania. The record of the earliest invasion is well documented in the penecontemporaneous Hardyston and Chickies Quartzites. The incoming sea must have found a deeply eroded topography. Abrupt changes in thickness of Hardyston Quartzite in eastern Pennsylvania and New Jersey may reflect the relief of the ancient landscape. The relatively coarse Chickies Quartzite with its basal Hellam Conglomerate member is doubtless a nearer-shore deposit than the thinner, finer-grained Hardyston Quartzite. Thinning northwestward, presumably perpendicular to the shore-line, represents recession from that shore-line and reduction in amount of transported materials seaward. Chickies Quartzite in Buckingham Mountain includes some beds with remarkably spherical quartz grains. If eolian, they hint of coastal dunes from which came the rounded sand grains of the Upper Cambrian limestones.

Passage from Chickies Quartzite upward into Cambrian dolomite has not been observed; that from Hardyston Quartzite is known. Although a local disconformity is indicated by Whitcomb (1949), in most places there is a transition from quartzite through phyllitic beds into the sericitic shale and limestone of the lower Tomstown Dolomite (Leithsville Limestone). Ripple marks, mud cracks and the abundant argillaceous content of the earliest dolomite point to two things: nearness to shore and shallowness of water. During deposition of about a thousand feet of this formation, there seems to have been little change in relative land-sea position. The recurrence of shaly beds, flaggy layers and massive strata in Tomstown Dolomite (Leithsville Limestone) is a rhythmic sequence which possibly reflects changes in acceleration of subsidence of the sea floor or uplift of the geanticline and concurrent variation in supply of sediments, and relative proportion of clastics to precipitates.

The contact between Tomstown Dolomite (Leithsville Limestone) and Conococheague (Limeport) Limestone is not definite. From all indications, the contact between the two formations is transitional. Physical evidence of passage from the older dolomite upward into

Conococheague (Limeport) Limestone is afforded by the advent of abundant stromatolites and oölites, the disappearance of or great reduction in the proportion of shale, and the loss of the stratal rhythm of Tomstown Dolomite (Leithsville Limestone). A few sandy beds and many well-rounded quartz grains are scattered throughout the younger carbonate rocks.

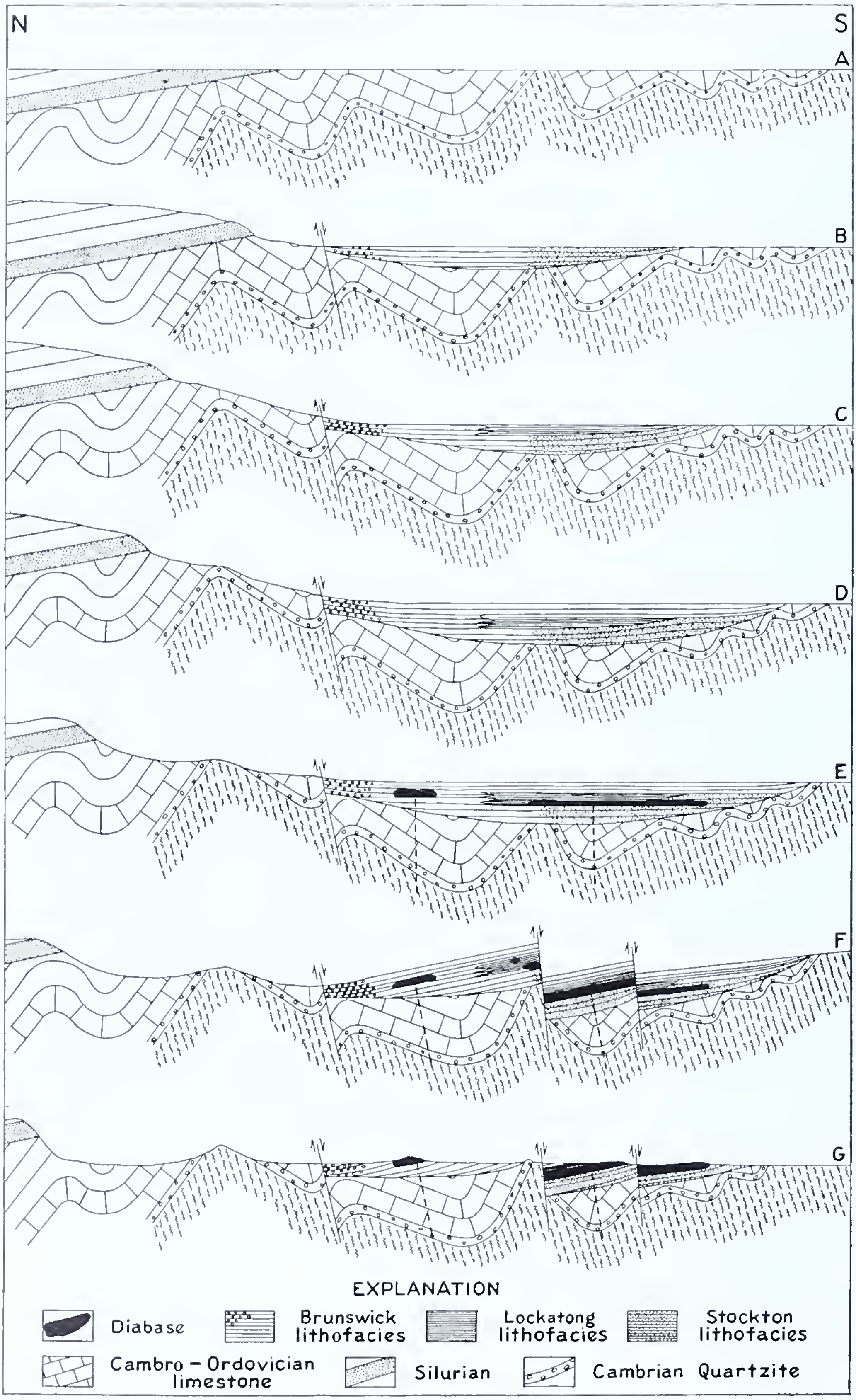
The numerous stromatolites of chlorophyl-bearing algae indicate a shallow water environment. The oölite confirms such a belief. Ripple marks do not necessarily connote shallow water conditions, but mud cracks, even though few and far between, are indicative of shoals. Absence of mud means clear water, possibly correlated with the rise of the algal biostromes. The well-rounded quartz grains suggest offshore gales which swept the dune sand of the Chickies Quartzite into the water. In the northern end of Bucks County, Conococheague (Allentown) Limestone succeeds Conococheague (Limeport) Limestone. Although concealed in Bucks County, the disconformity between these two is known in Northampton County. There it is drawn at an erosion surface which separates two distinct algal floras which are associated elsewhere with Dresbachian and Trempealeauian trilobites. The lost interval represents Franconian time. What its significance is or how widespread this disconformity may be are questions not yet fully answered. The Conococheague (Allentown) Limestone is so little different lithologically and paleontologically from Conococheague (Limeport) Limestone that conditions of genesis of both must have been quite similar. Each was deposited in a broad, shallow sea adjacent to a low-lying coast from which little sediment was derived except by winds blowing off shore.

The only Paleozoic rocks in Bucks County assigned to the post-Cambrian are the Ordovician Beekmantown (?) Limestone and Cocalico (?) Phyllite in the Buckingham area. Inasmuch as it overlies Conococheague (Limeport) Limestone of Dresbachian age, Beekmantown (?) Limestone is separated from the underlying Cambrian by a disconformity representing Franconian and Trempealeauian time. A red shaly band at the top of the Conococheague (Limeport) Limestone at the type locality is assumed arbitrarily to mark the top of that formation and hence the Cambrian-Ordovician boundary. The selection is poorly substantiated and can be applied only locally. Cocalico (?) Phyllite is a small, isolated patch, for which little can be done to rationalize its occurrence. It is referred to the Ordovician system because of its position and its similarity to Cocalico Phyllite in neighboring counties.

The absence of strata in Bucks County comparable to the Jacksonburg Limestone of the Lehigh Valley where that formation separates the Beekmantown Limestone from the overlying Martinsburg Shale is not surprising. In Bucks County the top of Beekmantown (?) Limestone is hidden beneath the overlapping Triassic rocks, and the base of Cocalico (?) Phyllite is downfaulted.

With the deposition of the Ordovician (?) formations of Buckingham Valley, the record of Paleozoic sedimentation in Bucks County ends. It is doubtful if younger Paleozoic systems ever extended far into Bucks County.

Figure 30



Reconstructed cross sections of Triassic of Delaware Valley to illustrate its chronologic development (from McLaughlin and Willard, 1949).

There is no direct proof in Bucks County of orogeny during the Taconic disturbance in late Ordovician time. Taconic structures cannot be isolated from those produced during the orogeny of the Appalachian revolution. One or both profoundly changed the attitudes of the Paleozoic formations in Bucks County, and further disturbed the Pre-Cambrian rocks. In the Slate Belt in northern Lehigh and Northampton Counties there is evidence (Behre, 1933b; and Miller, 1926) that both the Taconic and Appalachian orogenies affected the rocks. The Taconic disturbance was felt in eastern Pennsylvania probably as far as the Susquehanna Valley, but in diminishing intensity westward (Willard and Cleaves, 1939). In both orogenic intervals, the pressure is believed to have been exerted from the southeast.

The Lower Paleozoic formations in Bucks County were intensely folded and faulted prior to the deposition of Triassic sediments across the beveled edges of the Paleozoic rocks. Mountain-building, uplift, and profound erosion marked the final events at the close of the Paleozoic before the opening of the Mesozoic and the deposition of the Newark Group.

MESOZOIC

The record of the Mesozoic era in Bucks County is confined to beds assigned to late Triassic time, the Newark Group, and some concealed Cretaceous strata. As the latter are not certainly exposed, they are disregarded in this report. The following modified account of Triassic history is from McLaughlin and Willard (1949, p. 37-41). Figure 30 is a reprint of their Figure 1.

> It is our belief that the Lockatong represents lacustrine or swamp deposition, and it is in part synchronous with the fluviatile or torrentially-formed Brunswick. The Lockatong occupies the center of the wide Newark belt in the Delaware Valley where marshy conditions might have obtained. Lithology, stratigraphic sequence, distribution, facies changes both with and perpendicular to the strike indicate passage of the Lockatong into beds indistinguishable from the Brunswick. It is not improbable that the Stockton and Brunswick, too, are in part contemporaneous facies. The bases for the preceding statements may be demonstrated by summarizing the Triassic history of the Delaware Valley.
>
> Section A, Figure 30, is intended to show conditions at the end of the Paleozoic. The ancestral Appalachian Mountains, folded in the Appalachian Revolution, had been peneplaned. The surface sloped gently westward from Appalachia, whose crystalline rocks were bordered on the west by folded Lower Paleozoics and pre-Cambrian such as are today observable as the floor of the Triassic. Farther west, the surface cut successively younger Paleozoic formations. As the age of the rocks beneath the peneplane became younger westward, so, *pari passu,* did the uneroded thickness of the underlying sediments increase.
>
> Section B, early Newark time, indicates the inception of the Triassic basin. Uplift of the *thick,* folded Paleozoic formations on the west to initiate the present Appalachian Mountains, and simultaneous subsidence of the *thin* sequence of older formations to the east, adjacent to Appalachia, would constitute an orthodox interpretation of the tectonics. In conjunction with the foregoing, we suggest the following process, not necessarily as a substitute for the former, but as a contributing cause in the formation of the Triassic trough.
>
> The post-peneplane movements mentioned might be interpreted as a general eastward tilt from the region of folded, thick sediments across Appalachia. The pre-Triassic peneplane is traced in Figure 30, Section A. When uplift occurred, the less resistant rocks, limestones and shales, were eroded to form a long trough between the crystallines of Appalachia on the east and a developing escarpment of resistant Silurian strata on the west. This escarpment was the Triassic counterpart

of the present Kittatinny Mountain, but lay some 30 miles south of the present ridge of that name. As the valley floor approached base level, stream gradients were reduced within that depression, so that deposition eventually supplanted erosion. Such deposition built up the Triassic sediments indicated in Section B. Border faulting probably did not take place until considerable material had accumulated in the trough.

The hypothesis outlined is based partly upon observed or recorded contact relations of the Triassic. From Virginia to New York the Triassic overlies the Ordovician shales and phyllites, Cambrian and Ordovician limestones, Cambrian quartzite, and pre-Cambrian metamorphics. Where the Triassic abuts against gneiss at the northern border, there are often patches of limestone, and limestone conglomerate occurs in places where no limestone crops out today. In Pennsylvania the Triassic rests upon pre-Cambrian crystalline rocks with infolded Cambrian and Ordovician sedimentary rocks. This Triassic floor is essentially such as would be produced were the area of pre-Cambrian and early Paleozoic formations north of the present Triassic peneplaned. Bordering patches of limestone are of fortuitous occurrence, for the strike of the pre-Triassic elements is not always the same as that of the Triassic but is commonly at variance, usually by a few degrees. Therefore, the pre-Triassic exposed along the border differs from place to place.

As further support of our hypothesis, note that some of the border fanglomerates are composed of quartzite boulders derived from the Silurian. The backward cutting of the escarpment or ridge would have supplied this material. In this same vein, it must be recalled that in Triassic time there probably were no superimposed streams such as we have in the region today. Instead of carrying their loads across the basin and Appalachia to the sea, the Triassic rivers dumped their sediments in the eroded lowland. Fanglomerates of both limestone and quartzite phenoclasts mark where they debouched.

Long accumulated red regolith, formed from the sedimentary rocks of the peneplane to the west, was swept eastward into the new depression. That the uplift was relatively high and maintained by subsequent upward movements is inferred from the thick sequence of red sediments and the heavy border fanglomerates. Simultaneously, from the east, feldspathic sands, pebbles, and possibly some red mud streamed basinward from slightly uplifted Appalachia. That its uplift was relatively minor is deduced from the thinness of the Stockton and its eastward attenuated overlap onto the crystallines of Appalachia. As these two sources supplied sediments simultaneously, there could have been a mingling of the two lithofacies toward the basin axis.

By middle Newark time, Section C, the Triassic basin had widened. A thinning Stockton transgressed eastward onto degraded Appalachia. Off to the west further uplift maintained the supply of red sediments. Border faulting may have produced a scarp whose torrential streams built border gravel fans. With widening of the basin, its open, axial portion, remote from source of supply, became swampy, even lacustrine, received only fines from the west, little or no sediment from the east. Plants, crustaceans, fish, molluscs flourished. Black carbonaceous residues accumulated (Stevenson, 1948) in whose presence red ferric oxide was reduced to non-red ferrous compounds. Since comparative petrographic studies (Ryan, J. D., unpublished Master's Thesis on file, Lehigh University) of black Lockatong argillite and equally fine Brunswick red shale show closely similar mineral suites, an identical provenance is inferred. The Lockatong, like the Stockton, spread east a thinning wedge. In turn the Stockton was buried beneath the argillite.

Section D interprets the final Triassic uplift of the Appalachians, possible renewed faulting along the Triassic west border, deposition of additional fanglomerate and red beds. Up to this interval, the red beds had interfingered with the Lockatong. Now they spread into the central portion of the basin overwhelmed the Lockatong, obliterated the environment under which it had formed. Under analogous conditions of sedimentation in narrower parts of the Triassic belt without Lockatong, the later Brunswick overlapped the Stockton, left the impression of a normal sequence. In Section E, sheets of basic magma inject the Brunswick and Lockatong. These intrusives are assumed for simplicity to have been contemporaneous. There is a suspicion that the northern, stratigraphically higher, may be younger. The thinner, deeper bedded, more southerly intrusive had little effect upon the attitude of the strata, but the thick, shallow, northern sill of Coffman Hill is associated with downwarping of the adjacent sediments. The mechanism of the folding is obscure, but, since this sill was intruded during or near the close of Triassic sedimentation, the beds may have been sufficiently unconsolidated to permit settling through compaction. Isostatic adjustment and other possible causes may have contributed. The warping extended east into the Hunterdon Plateau.

Section F illustrates post-intrusion block faulting, rotating the blocks northwestward, thereby reversing the dips of the Brunswick, but accentuating those of the Stockton. Finally, in Section G, is presented the trace of the post-Triassic peneplane which reduced the region to its present surface. As the fault blocks were degraded, repetition of formations became more apparent in plan view.

After the Triassic events just described, the long interval of the Jurassic period was dominated by erosion and left no discernible record. In New Jersey the Cretaceous sediments overlap the attenuated eastern edge of the Triassic rocks. A similar relationship may once have existed in the southern part of Bucks County, but at present the southernmost Triassic is separated from the Cretaceous by the band of Pre-Cambrian and Cambrian rocks which crosses Bucks County in the vicinity of Langhorne.

TERTIARY AND YOUNGER DEPOSITS

No rocks which may be assigned to the Tertiary have been identified in Bucks County, but deposits of the Pleistocene and Recent are described by Peltier (Chapter V). The Tertiary history of Bucks County consists of continued erosion. During glacial times, a Wisconsin ice sheet briefly invaded the northeastern corner of Bucks County. All the other Pleistocene and Recent deposits are fluviatile or eolian.

As the Pleistocene ice ploughed into northeastern Pennsylvania, advance tongues drained down into the river valleys. Debris, pushed ahead of and melted out of the ice, became terminal moraines. For unknown distances south of the ice, climatic conditions were cold and wet. Abnormal weathering and erosion, accentuated by lack of vegetation and frost action, controlled the physiographic processes. Under such conditions the sill at Ringing Rocks became a boulder field. As the ice front commenced to retreat, melt water flooded the streams flowing south from the ice front. Their rampages are today recorded in terraces and flood plains of the Delaware River. Loess is recognized in the Delaware Valley.

The physiography of Bucks County is largely of pre-glacial ancestry. The main ridges, valleys, hills and flats originated prior to the ice age. Pleistocene and Recent modifications of the scenery are confined to the Delaware Valley.

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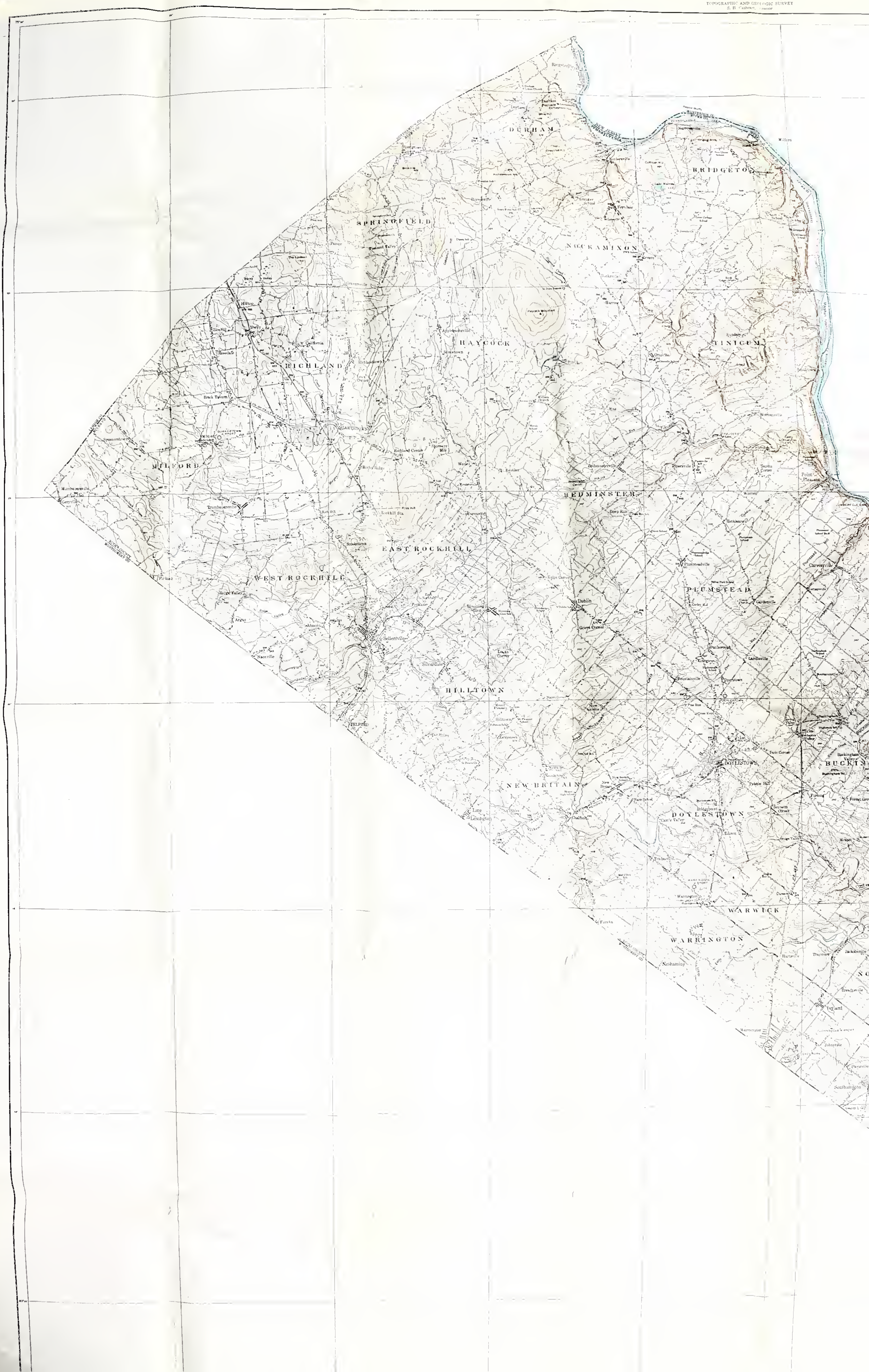
TOPOGRAPHIC AND GEOLOGIC SURVEY
S. H. Cathcart, Director



TOPOGRAPHIC MAP
OF
BUCKS COUNTY
PENNSYLVANIA

SOURCES OF TOPOGRAPHIC AND CULTURAL DATA

U. S. Army Map Service Quadrangles - 7½ minute series

Bedminster	Doylestown	Pennington	Stockton
Beverly	Frenchtown	Perkiomenville	Telford
Buckingham	Lambertville	Point Pleasant	Trenton East
Bristol	Langhorne	Quakertown	Trenton West
[illegible]	Milford Square	Riegelsville	

U. S. Geological Survey Quadrangles - 15-minute series

Allentown Germantown

Pennsylvania Department of Highways

Bucks County Highway Map — unpublished

- ★ BEACON
- BENCH MARK
- AIRPORT
- △ U S G S HORIZONTAL CONTROL POINT
- ● LOCATED OBJECT
- CANAL LOCK
- ▲ U S C & G S HORIZONTAL CONTROL POINT

Scale

Contour Interval 20 Feet

Datum is mean sea level

1950